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SHELF LIFE EXTENSION AND PATHOGEN REDUCTION OF FRESH CHICKEN THROUGH SURFACE PASTEURIZATION USING RADIANT HEAT AND ANTI-MICROBIAL AGENTS

By

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December 11, 1998

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MD. MAHBUBUL ISLAM

Shelf life extension and pathogen reduction of fresh chicken through surface pasteurization using radiant heat and anti-microbial agents.

(Under the direction of ROMEO TOLEDO)

Whole broilers exposed to a radiant wall (RW) at 649°C, for 0, 3, 4, 5, or 8 s or dipped in a solution containing 1% buffered sodium citrate, pH 5.8 (BSC), 0.5% citric acid (CA) or 2% liquid smoke (LS) prior to RW exposure. 5 s exposure reduced total plate count (TPC) 1.23 to 1.73 log without any noticeable change in organoleptic properties. Dipping in 1% BSC was synergistic with RW in reducing the TPC but CA and LS pre-treatments had no effect. TPC inside body cavity was not affected by radiant heat.

TPC of raw chicken drumsticks, dipped in BSC (6%) and exposed 3 s to a radiant wall (RW) at 788°C was reduced by 2 to 3 log, providing a shelf life of 27 d at 0°C vs. 13 d for controls and 18 d for RW treatment only. At 4°C, shelf life of BSC/RW treated drumsticks was 21 d vs. 10 d for control and 13 d for RW only treatment. Skin modification by different scald procedures affected shelf life of RW treated drumsticks: semi-scald (52°C) shelf life at 0°C was 29 d vs. 23 d for sub-scald (60°C) for similarly treated drumsticks.

No viable CFU of *Salmonella typhimurium* or *Campylobacter jejuni* were detected on raw chicken drumsticks inoculated with 1,000 CFU and exposed 3 s to RW at 788°C. There was no recovery from heat injury after 3 d refrigerated storage at 4°C. Challenge studies with large inoculum of each pathogen gave log reductions of 0.79, 1.73 and 2.32 for S. *typhimurium* on fresh chicken drumsticks treated respectively with only BSC, only RW and combined BSC/RW. Similar

treatments on *Campylobacter jejuni* yielded 1.45, 2.41, and 3.36 log reduction respectively.

INDEX WORDS: Pasteurization, Radiant heat, Poultry, Chicken, Antimicrobials, Sodium Citrate, Shelf life, Microorganisms, Pathogen, *Salmonella*, *Campylobacter*

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CHAPTER 1

INTRODUCTION

Poultry is one of the most widely accepted muscle foods in the world and is preferred by health conscious consumers as a low-fat alternative to beef. Over the last 50 years, poultry-meat production has undergone considerable expansion in much of the developed world. The industry has changed from an essentially family farm-based operation to one where economies of scale in rearing and processing have led to a high degree of operational efficiency. Processing, in particular, has become more mechanized, so that most stages in production of oven-ready whole broilers or cut portions are now either semi- or fully-automated, thus reducing labor costs and helping to maximize the speed and efficiency of the process. However, not all of the changes that have taken place have necessarily been in the best interests of maintaining product quality, e.g., in relation to meat tenderness and microbial contamination. Although poultry meat is rightly regarded as a wholesome, nutritious and cheap form of dietary protein, it is not without some problems. From the moment the bird is killed, the meat can support bacterial growth, which results in the production of off odors and discoloration.

Fresh poultry is extremely perishable. So, maintenance of shelf life is of primary importance. The shelf life of fresh poultry depends on the number of spoilage bacteria on the product immediately after processing and the holding temperature of the product during transportation, distribution and storage. Spoilage occurs when certain species of psychrotrophic bacteria multiply on

surface of chicken held at refrigeration temperatures and produce metabolic by-products that change the appearance, pH, or odor of the product.

Poultry transmitted diseases are major burdens on society causing considerable suffering and loss of productivity, and add to the cost of food production and health care. Among the diseases that can be acquired by ingesting undercooked or re-contaminated poultry or handling raw poultry, salmonellosis and campylobacteriosis are of primary concern in the United States. Risks of acquiring these diseases are greatly influenced by the prevalence of *Salmonella* species and *Campylobacter jejuni* in live birds and subsequently on poultry products. The origin of this problem lies with the large scale operations used in rearing and the processing the birds. Under such conditions, the transmission of a minority of the total resident microorganisms, e.g., *Salmonella*, occurs readily and cannot be easily prevented. Elimination of these gram-negative food-borne pathogens at the production level is currently not feasible. Therefore, an intervention step to substantially reduce or eliminate them during processing is desperately needed to ensure the safety of raw poultry product. Methods, which efficiently reduce microbial numbers, would afford the added benefit of extending the relatively short shelf life of fresh poultry.

Efforts to eliminate or substantially decrease bacterial population on poultry have been made by the poultry industry. With the exception of food irradiation, which has a high initial capital expense, few, if any processing technologies currently exist that significantly reduce or eliminate the microbiological hazards on the surface of raw poultry. Very rapid surface heating for a short time is thought to be an effective method in reducing the number of microorganisms on the surface. The original premise was that less heat would be

needed to kill organisms on a surface, than to cook that surface, due to the much higher activation energy of cooking, as compared to killing. Hence killing without cooking would depend on the rapidity of heating. To achieve this, we used a new type of oven, Radiant Wall Oven (RWO) (Fig. 1), in which whole chicken broilers/ chicken drumsticks were subjected to a very high temperature for a very short period. The surface of the chicken was heated by radiant heat in an attempt to kill the microorganisms on the surface without inducing noticeable organoleptic changes. Antimicrobial agents may also act synergistically with the radiant heat.

The objectives of the study were: to optimize time and temperature for radiant heat treatment of chicken, to extend the shelf life of chicken by reducing initial microbial counts by application of radiant heat and in combination with GRAS antimicrobial agents at different storage temperatures, to determine the efficacy of these combination treatments on *Salmonella typhimurium* and *Campylobacter jejuni* on fresh chicken and to measure the actual surface temperature of chicken due to the action of radiant heat on its microbial population.

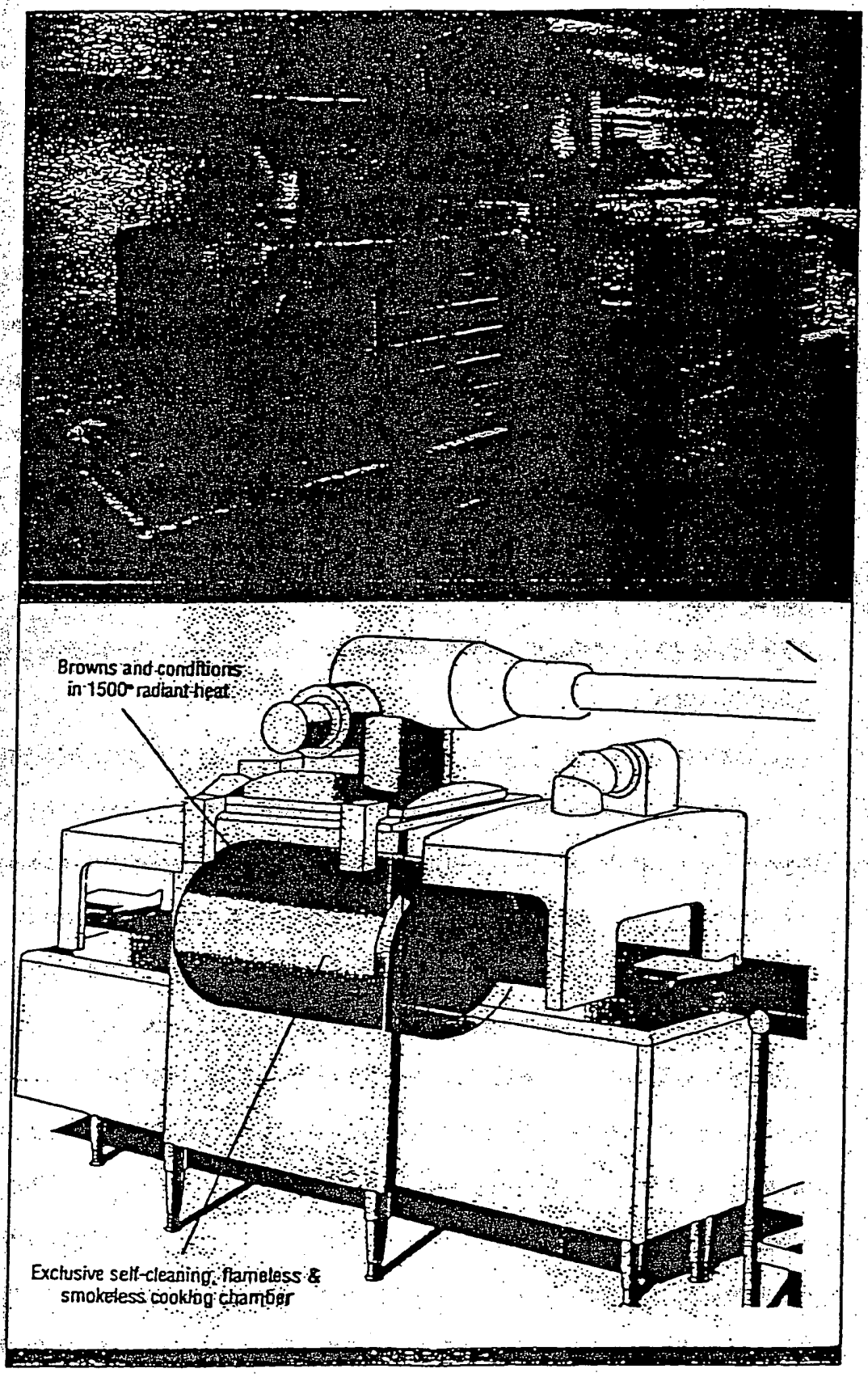

Fig. 1 : Radiant Wall Oven (picture and schematic)

CHAPTER 2

REVIEW OF THE LITERATURE

2.1. IMPORTANCE OF POULTRY PROCESSING INDUSTRY

Over the last few years there has been an increasing output of poultry meat and poultry meat products (USDA, 1998). Both national and international trade in poultry meat have increased (Simonsen, 1989). Twenty-four billion pounds of broiler chicken meat were processed in the United States in 1994 and approximately 80 % of this meat was sold fresh (Russell, 1997). Per capita consumption data for chicken in the USA are shown in Table 1 covering 1989 to 1998. During this period per capita consumption of chicken meat has increased from 68 to 88 pounds. In 1998, estimated production of chicken is more than 29 billion pounds.

2.2. TYPES OF MICROORGANISMS ASSOCIATED WITH FRESH CHICKEN

Poultry meats are derived from warm-blooded animals. Their microbial flora is heterogeneous, consisting of mesophilic and psychrotrophic bacteria from the animal itself, soil and water bacteria from the environment, and bacterial species introduced by man and equipment during processing (Grau, 1986; ICMSF, 1980). The widespread sale and use of raw chicken demands closer attention to their microbiology. Chilled or frozen, chicken may be marketed as whole, whole cut-up, bone-in parts or deboned. With few exceptions, bacterial growth is a surface phenomenon in raw poultry products. The quality of the chicken meat is considered optimum immediately after processing, and maintenance of acceptable quality depends on initial microbial levels and measures taken to minimize the growth of organisms. The two major concerns

are control of spoilage organisms which cause consumers to reject the product due to unacceptable odor or flavor, and minimization of pathogenic organisms which may, under prolonged storage or faulty handling, lead to a health hazard (Cunningham, 1987).

TABLE 1: PRODUCTION AND PER CAPITA CONSUMPTION, READY-TO-COOK CHICKEN IN THE UNITED STATES, 1989-98

Year	Production			Consumption	
	Commercial broilers (Million pounds)	Other Chickens (Million pounds)	Total[1] (Million pounds)	Total[3] (Million pounds)	Per capita (Pounds)
1989	17,227	531	17,758	16,886	68
1990	18,430	523	18,953	17,762	71
1991	19,591	508	20,099	18,751	74
1992	20,904	520	21,424	19,826	78
1993	22,015	515	22,530	20,520	79
1994	23,666	509	24,175	21,103	81
1995	24,827	496	25,323	21,238	81
1996	26,124	491	26,615	21,854	82
1997[2]	27,061	509	27,570	22,509	84
1998[4]	28,556	530	29,086	23,876	88

[1] Totals may not add due to rounding
[2] Preliminary
[3] Shipments to territories included
[4] Forecast
(Source: USDA, Agricultural Statistics, 1998, page VIII-37)

The chief microbiological concerns associated with fresh chicken center around two types of microorganisms - psychrotrophs that grow during extended refrigerated storage and mesophiles, which grow in the product subjected to

temperature abuse. Psycrotrophs are bacteria, yeast, and molds that grow, although slowly, at refrigeration temperatures (below 7°C) but grow optimally at temperatures above refrigeration, e.g., 25°-30°C (Marth, 1998). Their maximum growth temperatures are 30°-35°C (Kraft, 1992; Olson and Nottingham, 1980). Mesophilic microorganisms could survive under refrigerated storage and grow when food is temperature-abused. Mesophiles grow well between 20°-45° C with optimum growth between 30°-40° C (Jay, 1992). The potential for psychrotrophic spoilage microorganisms to grow during the extended refrigerated storage period and decrease organoleptic quality or spoil the food product is a concern. Additionally, psychrotrophic and mesophilic pathogens are also present on poultry.

The surface flora on freshly slaughtered carcasses, usually about 10^2 to 10^4 bacteria per square inch, is primarily mesophilic, having originated from the alimentary tract and external surfaces of the live animal. Contamination from the slaughtering environment is also largely mesophilic in nature since this process occurs in rooms ambient in the summer and heated in the winter (Barnes, 1976). Psychrotrophic organisms originating from soil and water are present but usually only to about 10^1 per square inch (Surkiewicz et al., 1969). The mesophiles are important because they indicate the effectiveness of sanitation practices in the processing plant. Populations of bacteria on surfaces of raw poultry carcasses at the end of processing vary, but typically the range is from 10^3 to 10^5 aerobic mesophillic organisms per inch^2 (ICMSF, 1980). Because the post-processing environment is frequently refrigerated, a low-level recontamination with psychrotrophic bacteria almost always occurs. The psychrotrophs are important because they increase in numbers even though the products are stored at proper

refrigeration temperatures. They ultimately cause spoilage and thus determine the shelf life of the product. When chicken is held under refrigeration, the micro flora begins to shift toward psychrotrophs of the *Pseudomonas-Acinetobacter-Moraxella* group (Barnes, 1976). Earlier studies by Barnes and Impey (1969) found that the organisms most commonly found growing on poultry carcasses at low temperatures (around 1°C) were pigmented and non-pigmented species of *Pseudomonas*, *Pseudomonas putrifaciens*, and strains of *Acinetobacter*. These authors also noted that *P. putrifaciens* grew much faster on leg muscle than on breast, and explained this on the basis of a difference in pH - leg muscle having pH 6.4 - 6.7, and breast 5.7 - 5.9. In an earlier report (Ayres 1959), it was stated that the microbial population responsible for spoilage of the refrigerated product (4°C) was psychrotrophic. After 12 days storage, the dominant psychrotrophic population was 90% *Pseudomonas-Achromobacter*. Pseudomonads were the most significant Gram negative rods associated with spoilage of poultry.

2.3. IMPORTANT PATHOGENIC MICROORGANISMS IN CHICKEN

The presence of pathogens in raw poultry is a public health concern. Although efforts are being made to reduce this contamination, none of the currently available procedures can provide pathogen-free raw poultry. *Campylobacter*, *Staphylococcus aureus*, *Listeria monocytogenes*, and *Salmonella* are often present on fresh poultry because the steps involved in the slaughtering process are inadequate to eliminate these organisms. Although the recently mandated Hazard Analysis Critical Control Points (HACCP) procedures have reduced the incidence of pathogens in fresh poultry, there are still a substantial percentage of the product which harbor the pathogens. The level of coliforms has been commonly used as an indicator of hygienic conditions in the

handling of fresh poultry and the microbiological quality of meat and poultry products. However, since multiplication of certain psychrotrophic coliforms will occur during refrigerated storage, the coliform results lose their significance as an indicator of the hygienic conditions during production when sampling is done at a later stage in storage. This is also one, among several, reasons why coliform values are not an effective indicator of the safety of refrigerated poultry products. Although several bacterial pathogens have been associated with poultry-borne human illnesses, *Salmonella* and *Campylobacter jejuni* are of primary contemporary concern. These are major human pathogens and poultry and poultry products are frequent vehicles of these bacteria (Bryan and Doyle, 1994). Public health officials estimate that *Campylobacter* isolates are responsible for 1.1 million to 7 million food borne infections and 110 to 1000 deaths per year. By comparison, food borne *Salmonella* sickens some 700,000 to 4 million people, though deadlier than campylobacters, killing up to 2000 per year (Anon. 1998). Costs associated with human salmonellosis in the United States have been estimated to be from 1-2.3 billion dollars annually and that for campylobacteriosis have been estimated to be between less than a million to 1.4 billion dollars annually (Bryan and Doyle, 1994). USDA estimates that approximately 40% of all raw poultry is contaminated with *Salmonella* (Sugarman, 1992). Although the reported occurence of *C. jejuni* in poultry ranges from 0 to 100%, the median is 62 % positive (Bryan and Doyle, 1994). The presence of these bacteria in poultry products could lead to human illnesses, deaths and associated costs to the poultry industry and consumers of poultry products.

2.4.1. *Campylobacter* spp.

Campylobacter was recognized as an animal pathogen long before it was identified as human pathogen responsible for gastroenteritis (Franco and Williams, 1994). Before 1972, when methods were developed for its isolation from feces, it was believed to be primarily an animal pathogen causing abortion and enteritis in sheep and cattle. Their importance as a cause of human diarrhea has been recognized only relatively recently and was quickly elucidated that many outbreaks of *Campylobacter* enteritis had a food origin. *Campylobacter jejuni* was responsible for most such outbreaks (CDC, 1988).

Campylobacters are Gram-negative, highly motile, small, spiral-shaped cells. They are microaerophillic organisms, which means they have a requirement for reduced levels of oxygen. They are relatively fragile, and sensitive to environmental stresses (e.g., 21% oxygen, drying, heating, disinfectants, acidic conditions). The genus has been reviewed by Penner (1988). Campylobacteriosis is the name of the illness caused by *C. jejuni*. It is also often known as *Campylobacter* enteritis or gastroenteritis. The most common clinical symptoms of intestinal infection with *C. jejuni* are abdominal pain, fever and diarrhea, sometimes accompanied by vomiting. Pain and fever may precede diarrhea. Diarrhea may be profuse, watery and frequent or alternatively bloody. In the dysentery-like syndrome, fresh blood, mucus and leucocytes are found in the stool (Walker *et al.*, 1986). Although diarrhea may be severe, dehydration is usually only a problem in the young or elderly. The illness usually occurs 2-5 days after ingestion of the contaminated food or water. Illness generally lasts 7-10 days, but relapses are not uncommon (about 25% of cases). Most infections are self-limiting and are not treated with antibiotics. However,

treatment with erythromycin does reduce the length of time that infected individuals shed the bacteria in their feces. The organism may be excreted in the feces for several weeks. Bacteraemia is rare. Illness is caused by infection of the intestinal tract. Illness has been caused by the ingestion of as few as 500-800 cells in milk (Robinson, 1981; Black *et al.*, 1983). The mechanisms by which *C. jejuni or C. coli* cause diarrhea are suggested by the clinical symptoms. Secretory or watery diarrhoea may be caused by organisms adhering to the mucosa in the proximal small intestine and forming an enterotoxin (McCardell *et al.*, 1984, 1986). Over 70% of *C. jejuni* strains also produce a cytotoxin (Johnson and Lior, 1986; Walker *et al.*, 1986). Cytotoxin could be important in bloody diarrhea. Recent studies suggest that *Campylobacter* infection may be linked to Guillain-Barre Syndrome, Reiter's Syndrome and other forms of neuromuscular paralysis (Smith, 1995).

Since foods may contain only a few cells, liquid enrichment methods are normally required before selective plating in order to detect contamination with *C. jejuni*. Successful detection of these organisms requires incubation at 42°C under microaerobic conditions (5% oxygen and 10% carbon dioxide). For isolating *C. jejuni* from chicken carcasses, a blood-free charcoal-based agar (CCD blood-free agar) appears to be at least as selective as blood-containing selective agars in restricting the growth of contaminants while allowing good growth of *Campylobacter* colonies (Bolton *et al.*, 1986). *Campylobacter* colonies are non-hemolytic and may be flat, spreading and with an irregular edge or discrete, circular-convex and 1-2 mm in diameter. Suspect colonies are examined microscopically for the characteristic morphology and darting motility of

campylobacters. Campylobacters in food can be enumerated either by an MPN technique or by direct plating.

The intestinal tract can harbor *C. jejuni and C. coli* with no evidence of illness in a wide variety of wild and domestic warm-blooded animals (Franco, 1989; Skirrow, 1991). Campylobacters may infect man after direct contact with animals or indirectly via contaminated water, milk or meat. Since *C. jejuni* is regularly found on retail raw poultry, poultry is the largest potential source of *Campylobacter* for humans (Blaser *et al.*, 1984). The consumption of rare or under-cooked poultry has been implicated in a number of small outbreaks (Skirrow, 1982; Blaser *et al.*, 1984; Istre *et al.*, 1984; Rosenfield *et al.*, 1985). Sporadic cases of *Campylobacter* enteritis vastly outnumber the cases seen in outbreaks and poultry is believed to be responsible for many of the sporadic cases (Stern,1992; Kaijser, 1988). Harris *et al.* (1986) estimated 48% of campylobacteriosis cases were due to consumption of contaminated chicken. It has been proposed that human infection is more likely from chilled than from frozen chicken because of the higher numbers of campylobacters surviving on the former (Hood *et al.*, 1988). At retail outlets, campylobacters are present in higher numbers on chilled-fresh than on frozen chicken (Gill and Harris, 1984; Hood *et al.*, 1988). Campylobacters can be isolated from freshly slaughtered red-meat carcasses, but in smaller numbers than on poultry (Doyle, 1984).

Campylobacter jejuni is relatively sensitive to the lethal effects of heat, D_{55} values ranging from 0.6 to 2.3 min (Roberts, et al., 1996). The heating milieu appears to have only a small influence on heat sensitivity, except that cells heated in 0.1 M phosphate buffer (pH 7.0) exhibit a significantly faster loss of viability compared with cells heated in peptone solutions or in foods (Gill and

Harris, 1984). Maximum heat resistance occurs at near pH 7.0, and decreases as pH moves away from neutrality. z-values range from 4.5 to 8.0 for temperatures between 48 and 60°C (Roberts, et al., 1996). Campylobacters are readily destroyed by pasteurization. Pasteurization is a critical control point in preventing human infection. *C. jejuni* is at least as sensitive as *E. coli* to chlorine and chloramine (Wang *et al*, 1983; Blaser *et al.*, 1986). Proper chlorination of drinking water and maintenance of distribution systems are critical control points in preventing infection by waterborne campylobacters.

There are two ways in which *C. jejuni* on raw meats can remain present on foods ready for consumption: the meats may be eaten raw or undercooked, or, probably more importantly, campylobacters may be transferred from raw meat to ready-to-eat foods. *C. jejuni* is readily destroyed by cooking at temperatures of 55-60°C for several minutes. Control also requires precautions to avoid cross-contamination when preparing meals. Handling raw poultry or offal meats can lead to the contamination of hands, surfaces and other foods. Blood and chicken thaw-liquor have protective actions and markedly increase the survival time of camplylobacters (Coates *et al.*, 1987). Cooked meats and other foods can be recontaminated if placed on plates or surfaces that have held raw meats. Washing and drying hands removes even heavy inocula of *C. jejuni*. However, kitchen staff often merely rinse their hands without thorough drying (Coates *et al.*, 1987). Auto-infection may take place directly by the hand-to-mouth route during food preparation.

Campylobacter jejuni has moved from relative obscurity in the 1970s to a prominent position as a foodborne diarrheic pathogen in the 1990s and is the most common bacterial cause of enteritis in the United States (Tauxe, 1992).

However, it can not be dismissed as only a cause of a temporary, inconvenient gastrointestinal infection. It is now realized that *C. jejuni* is a cause of severe neuromuscular paralysis. Most of the burden to the public from infection by *C. jejuni* is economic: the cost of gastrointestinal illness induced by the organism is enormous and if that cost is coupled with the presently unknown costs of *C. jejuni* complications, the economic liability is unacceptably high (Smith, 1995).

2.4.2. *Salmonella* spp.

A major health concern in poultry is the well-known association of pathogenic microorganisms of the *Salmonella* group with the poultry production environment. Poultry is still considered to be the single most important source of salmonellae (Cunningham, 1987). In most cases, careless handling of foods before consumption has been primarily responsible for the food borne illness like salmonellosis. *Salmonella* is not a heat-resistant organism and properly handled and/or cooked poultry constitutes no health hazard. Cross contamination to other food that are not cooked are the main concern.

Salmonella was recognized as a food borne pathogen before this century and has become recognised as a major cause of enteritis throughout the world (Bryan and Doyle, 1994). Budd (1874) was first to infer that typhoid fever was transmitted by water and food. *Salmonella typhi*, the etiological agent of the disease, was discovered in 1880 by Eberth and isolated in 1884 by Gaffky. *S. cholerae-suis* (the type species) was isolated from swine clinically diagnosed having hog cholera (Salmon and Smith, 1885). The genus name was coined by Lignieres in 1900 in honour of Dr Salmon's work. The first laboratory-confirmed outbreak of food borne salmonellosis involved 57 persons who ate meat from a sick cow. *S. enteritidis* was isolated from the organs of a victim who had not

survived and from the meat and blood of the animal. Since then, salmonellae have become recognized as a major cause of enteric fever and gastroenteritis.

Salmonella is a genus of the family Enterobacteriaceae (Brenner, 1984). Members of the family are characterized as Gram-negative, facultatively anaerobic, non-spore-forming, rod shaped bacteria. Motile forms have peritrichous flagella. Most members of this family are found in the intestinal tract of man and other animals as either pathogens or commensals. Approximately 2200 serovars of *Salmonella* have been identified (Brenner, 1984; Ewing, 1986). Different serotypes dominate in different parts of the world, but it seems that *S. typhimurium* is the type most frequently encountered. Other important species include *S. enteritidis, S. heidelberg, S. agona, S. newport, S. infantis, S. panama, S. saint paul and S. welteveden.*

Salmonellosis remains one of the three most common food borne diseases, and poultry and poultry products are the major source of salmonellosis in man (Silliker, 1982; Bryan, 1980 and 1981; Todd, 1980). The annual estimate of cases is 160,000 for Canada and 1,300,000 for the U.S.A., with medical costs in the U.S.A. exceeding $1.2 billion (Bryan and Doyle, 1994). Major syndromes of salmonellosis are enterocolitis or gastroenteritis, enteric fever, bacteremia and fecal infection of various organs that may follow bacterimia. Common signs and symptoms of gastroenteritis are diarrhea, nausea, abdominal pain, mild fever and chills. The incubation period ranges from 5 h to 5 days, but signs and symptoms usually begin 12-36 h after ingestion of a contaminated food. The syndrome usually lasts 2-5 days. For enteric fever, the incubation period ranges from 7 to 28 days. Malaise, headache, high persistent fever, abdominal pain, body aches and weakness occur, commonly with either pea-like diarrhea or constipation.

Nausea, vomiting, cough, perspiration, chills and anorexia may occur. Rose spots sometimes appear on the trunk, back and chest. A slow heart rate, a tender and distended abdomen, enlarged spleen, and sometimes bleeding from the bowel or nose are observed. The senses are dulled and patients may become delirious. Relapses sometimes occur. Convalescence is slow (1-8 weeks). Bacteraemia or septicaemia is caused by the presence of salmonellae in the blood. The result is a high, persistent fever, pain in the back, abdomen and chest, chills, perspiration, malaise, anorexia and weight loss. The condition may be transient or chronic. Strains of *S. typhimurium*, *S. cholerae-suis* and *S. dublin* are liable to invade the bloodstream and fecal infections of various tissues may follow. Although uncommon, identified sequelae include: appendicitis, arthritis, cholecystitis, endozditis, local abscesses, meningitis, osteomyelitis, osteoarthritis, pericarditis, peritonitis, pleum, pneumonia and urinary tract infection (Archer and Young, 1988; Smith et al., 1993).

Early studies in human volunteers indicated that the ingestion of more than 10^5 salmonellae was typically required to cause illness in previously healthy adults (McCullough and Eisele, 1951). In some instances, however, particularly when the vehicle has been either water or fatty or buffered foods, small numbers (e.g.< 100/g) of salmonellae have been found in the epidemiologically implicated foods (D'Aoust and Pivnick, 1976; Blaser and Newman, 1982).

Routine detection of salmonellae involves a sequence of pre-enrichment, enrichment, selective differential plating, isolation and identification. Incubation times are usually 16-24 h. Normally, incubation temperatures range from 35 to 43°C, although incubation at 41-43°C often results in increased detection of salmonellae. Commonly used selective broths include tetrathionate with brilliant

green and selenite with cystine. The presence of salmonellae is determined by plating samples of enrichment broths on selective plating media. Commonly used selective plating media include brilliant green, bismuth sulphite, Hektoen enteric agar, MacConkey, deoxycholate citrate and *Salmonella-Shigella* agars. Salmonellae are enumerated by the most probable number technique (ICMSF, 1978; Speck, 1984) and direct plating.

Salmonellae are found worldwide and are universally recognized as zoonotic agents. Salmonellae reside in the intestinal tract of infected animals (including human beings). Foods of animal origin become contaminated following fecal contamination of the environment and equipment. Cross-contamination is produced by contaminated raw foods during further processing and preparation. *Salmonella* can also become established and multiply in the environment and equipment of a variety of food-processing facilities. Turkey and chicken meats are frequently identified as vehicles in outbreaks of salmonellosis. Poultry carcasses and parts are frequently contaminated with salmonellae, which reach carcasses from the intestinal tract or from fecal material on feet and feathers. Cross-contamination is a particular problem, and critical steps include defeathering, evisceration and chilling. Cross-contamination of the hands of workers and of equipment and utensils can spread the bacterium to uncontaminated carcasses and parts, contamination continuing during subsequent processing, cut-up and preparation activities. Besides, eggs, milk, water and some non-animal origin foods like coconut, barley, cereal powder, yeast, cottonseed, chocolate candy, soybean sauce, cider, watermelon, white pepper, black pepper and carmine dye have been identified as vehicles of

salmonellae. The importance of *Salmonella* in foods in international trade is comprehensively reviewed by D'Aoust (1994).

The minimal growth temperature is important in refrigerated foods. The growth rate of salmonellae is substantially reduced at < 15°C, while the growth of most salmonellae is prevented at <7°C. Slow growth in foods that are stored for extended periods in chilled conditions (but within the growth range for salmonellae) is of particular concern. Storage of perishable foods at temperatures below the minimum for growth is essential for safety. As the maximum temperature for growth is exceeded, death occurs. The rate increases with increasing temperature. The maximal growth temperature (49.5°C) is important as a value above which hot-stored foods must be maintained to prevent the growth of salmonellae. Although 55°C would suffice, 63°C is often specified in regulations. Although freezing can be detrimental to salmonellae, it does not guarantee destruction of salmonellae in food. *Salmonella* are sensitive to heat and heat-resistant strains are rare. An example is the unique strain 775W of *S. seftenberg*, which is considerably more resistant than other salmonellae in moist foods. Heat resistance is influenced by the water activity, nature of the solutes and pH of the suspending medium. Heat resistance increases as the water activity of the substrate decreases. Reducing pH reduces heat resistance.

Although salmonellae do not form spores, they can survive for long periods in foods and other substrates. Salmonellae survived longer than 10 weeks in butter stored at temperatures between - 23 and 25°C (Sims *et al.*, 1969) and for 6 months in milk stored at room temperature or in an ice box (Berry, 1927). On a range of vegetables, including green beans, beets, cabbage, carrots, celery, cucumbers, lettuce, peppers, radish, spinach and tomatoes,

salmonellae consistently survived for more than 28 days at 2-4°C and about half that time at room temperature (Felsenfeld and Young, 1945). Their survival in the dry environment of chocolate is remarkable, numbers declining only slightly over months in milk chocolate (a_w = 0.32-0.41) or bitter chocolate (a_w = 0.30-0.51) (Tamminga, et al., 1977). Salmonellae also survive well on surfaces such as ceramic, glass and stainless steel (MeDade and Hall, 1964) and on human skin (Pether and Gilbert, 1971).

Since low numbers of salmonellae can cause illness, it is important to ensure their absence from ready-to-eat foods (Bryan, 1981). The major control procedures involve: A kill step to assure the destruction of salmonellae in contaminated foods, especially raw agricultural products of animal origin, prevention of contamination of ready-to-eat foods with salmonellae and low-, or high-temperature storage of foods that prevent the growth of salmonellae. The consequences of these bacteria in poultry products causing human illnesses will continue unless some means is devised and implemented that will either eliminate these bacteria from poultry or drastically reduce their contamination.

2.5 MEASURES TO CONTROL MICROORGANISMS ON POULTRY SURFACE

There is an immediate need for a cost-effective approach to reducing the prevalence of spoilage and pathogenic microorganisms on poultry to make it safer and more shelf-stable. Efforts to eliminate or substantially decrease bacterial populations on poultry have been made by the poultry industry. A variety of antimicrobial treatments for broiler carcasses have been investigated, with primary focus on those that are practical and effective. Major technologies that are employed to ensure the microbiological safety of poultry include (i) procedures that prevent the access of microorganism, (ii) procedures that

inactivate them should they have gained access, and (iii) procedures that prevent or slow down their growth should they have gained access and not been inactivated. Traditional preservation procedures act in one of these three ways.

Hot water

The USDA's Food Safety and Inspection Service (FSIS) recently approved the use of hot water ("…..heated to any temperature provided sufficient safeguard exist") as an acceptable antimicrobial treatment during final washing of carcass (USDA, 1994a). However, hot water immersion study by Cox et al. (1974) demonstrated that broiler carcasses subjected to 60°C water treatment exhibited a partially cooked appearance.

Chlorine

One approach has been the application of decontamination treatments to carcasses during processing (Todd, 1980). During poultry slaughtering, birds are killed, defeathered, eviscerated, cleaned and chilled by immersion in cold water. Currently, chlorine is used in chiller water to reduce microbial populations on poultry carcasses during immersion. Chlorine is used because of its generally recognized as safe (GRAS) status, efficacy, availability and relatively low cost (Tsai et al., 1991). However, production of off flavor, carcass discoloration and possible formation of chlororgenic compounds as a result of exposing poultry to free chlorine (Cunningham and Lawrence, 1977) has prompted a need for investigating alternative methods to decontaminate carcasses.

Hydrogen peroxide

Hydrogen peroxide at 6,600 ppm or higher in chiller water has been shown to reduce populations of aerobic microorganisms by 95-99.5%; 5,300 ppm or higher reduced populations of *Escherichia coli* by 97-99.9 % (Lillard and

Thomson, 1983). However, the reaction of hydrogen peroxide with catalase from broiler carcasses causes discoloration and swelling (Hwang and Beuchat, 1995). Fletcher, et al., (1993), in a three-step rinse process using sodium bicarbonate and hydrogen peroxide solutions to decontaminate broiler surface achieved only 0.3 $\log_{10}$ reduction. He observed that it is questionable whether the level of bacterial reduction would justify the use of such a procedure in lieu of other available methods.

Trisodium phosphate (TSP)

A process using food-grade orthophosphate (TSP) to reduce viable *Salmonella* spp. on chicken carcasses has been approved by USDA (Giese, 1993). This process has been reported to reduce populations of *Salmonella* spp. (Geise, 1993; 3M, 1994), *E. coli* (Geise, 1993), *Campylobacter* (Stern, et al., 1985) and *S. aureus* (Lee, *et al.*, 1994) on chicken, but the population reduction on total aerobic microorganisms (3M, 1994) is much less.

Organic acids

Organic acids have been investigated because of their bactericidal activity and because they are generally recognized as safe (GRAS). They are utilized as preservatives in many food applications. Mountney and O'Malley (1965) studied the use of organic acids to increase the shelf life of poultry. Acids were most effective in the following order: acetic, adipic, succinic, citric, fumaric, and lactic, but the use of acetic acid caused the skin of the poultry to be hard and leathery. Reynolds and Carpenter (1974) also noticed discoloration and residual off-odor in pork carcasses treated with 2.32 M acetic acid. Lactic acid (1%) reduced *Salmonella typhimurium* from pure cultures and from inoculated broiler carcasses (Mulder et al., 1987); however, such treatment was later shown to

discolor the meat (Izat et al., 1989). Citric acid was found to be most inhibitory to *Salmonella* and as little as 0.3 % citric acid lowered the level of these organisms on poultry carcasses (Thomson et al., 1967). Further evaluation of organic acids may provide an economical and effective means of controlling microbial contamination during processing.

Other chemicals

Treatment with ozone (Sheldon and Brown, 1986), potassium sorbate (Robach and Sofos, 1982), chlorine dioxide (Lillard, 1980; Thiessen et al., 1983), sodium lactate (Zeitoun and Debevere, 1980) and glutaraldehyde (Thomson et al., 1977) have been shown to reduce microbial population on poultry carcasses. However, factors such as cost or adverse sensory changes that can result from treatment with these chemicals has prevented their usage (Hwang and Beuchat, 1995).

Irradiation

Ionizing radiation is effective in decontaminating poultry carcasses (Mulder et al., 1977) but its application may be limited by consumer acceptance. Moreover, it has a high initial capital expense and is difficult to incorporate in existing processing line.

Modified Atmosphere Packaging/ Vacuum packaging

The use of modified atmosphere packaging for extension of shelf life of fresh poultry was investigated (Finne, 1982) with some success. Huang (1978) observed slower growth rate of spoilage microorganism in chicken cut-up parts in vacuum packaging. However, there is a big risk of growth of any facultatively anaerobic or anaerobic psychrotrophic pathogen. Also, the process is expensive for a product like fresh chicken.

Other control measures

Ultrasonic energy (Sams and Feria, 1991) and ultraviolet radiation (Stremer et al., 1987) treatments have also been considered, but were ineffective for products with irregularly shaped surfaces. Other potential non-thermal methods to extend shelf life such as, Pulsed Electric Fields(PEF) and Pulsed High-intensity Light (PHIL) technology (Yousef, 1996), High Hydrostatic Pressure (HHP) Raffalli et al., 1994), Bacteriocins (Shefet, et al., 1995) etc. were studied with limited success. Flash steam heating followed by evaporative cooling (Morgan, et al., 1996, Cygnarowicz-Provost, 1994) was reported to be effective in some cases. These methods are not yet fully developed nor commercially applied.

2.6 CITRIC ACID AND SODIUM CITRATE AS ANTIMICROBIAL ADDITIVES

Citric acid is a tricarboxylic acid having a pleasant sour taste and is found in a variety of natural foods. It is highly water soluble and enhances the flavor of citrus-based foods. It is approved for use in ice cream, sherbets and ices, beverages, salad dressings, fruit preserves, and jams and jellies, and it is used as an acidulant in canned vegetables and dairy products. It is a precursor of diacetyl and therefore indirectly improves the flavor and aroma of a variety of cultured dairy products. It can control the pH for optimum gel formation. Citric acid also acts synergistically with antioxidants to prevent rancidity by chelating metal ions (Gardner, 1972). Citric acid is approved as a GRAS substance for miscellaneous and general-purpose usage, in the acid form (21 CFR 182.1033) or as the calcium (21 CFR 182. 1195), potassium (21 CFR 182.1625), or sodium salt (21 CFR 182. 1751) (Code of Federal Regulations, 1977).

Murdock (1950) reported that citric acid was particularly inhibitory to flat-sour organisms isolated from tomato juice. Little bacteriostatic, activity was noted at pH 5.0, but with lowering of pH level, the inhibition increased. Fabian and Graham (1953) compared citric, acetic, and lactic acids with respect to inhibition of thermophilic bacteria. Citric was the acid of choice, followed by acetic and lactic. Skim milk acidified with hydrochloric, lactic, or citric acid was inoculated with *S. typhimurium*. Citric acid was found to the most inhibitory to the salmonellae, followed by lactic and hydrochloric acids (Subramanian and Marth, 1968).

Concentrations of 12-12.5% sodium citrate were inhibitory to *S. anatum* and *S. oranienburg* (Davis and Barnes, 1952) . As little as 0. 3% citric acid lowered the level of salmonellae on poultry carcasses (Thomson et al.,1967). Sodium citrate in concentrations of 0.1-4.0% were not inhibitory to *Streptococcus agalactiae* when added to skim milk or fresh milk; however, citric acid at 1, 2, and 4% was inhibitory. The minimum inhibitory concentration was judged to be 0.8%, which gave a pH of 4.08- 4.12 (Sinha et al. , 1968). The amount of sodium citrate had a dual effect on *Lactobacillus casei* (Imai, et al., 1970). In concentrations of 12-18 μM/ml, sodium citrate was found to be stimulatory, whereas in concentrations greater than 40 μM/ml, *L. casei* was inhibited. Chelation of metal ions by citrate may be the cause of the inhibition (Branen and Keenan, 1970). Experiments using *S. aureus* showed inhibition both with increasing concentrations of citrate and decreasing pH. It was believed that citrate was a chelator of ions essential for growth. Inhibition by citrate could be overcome by adding Ca^{2+} and Mg^{2+} ions (Rammell, 1962).

2.7 HEAT PASTEURIZATION

Heat treatment and low temperature storage are two of the main methods of food preservation. Refrigeration has the advantage of leaving organoleptic properties and nutritive value of foods almost unchanged. However refrigeration does not necessarily ensure food safety. Heat, with its destructive effect on microorganisms ensures safety and longtime preservation, but the effects of heat on foods can also be very detrimental. Some thermal processings cause significant drastic changes in organoleptic properties and reductions in nutritive value. As no other method of food preservation to replace heat has yet been developed, a new approach in food preservation has arisen. This is the combination of heat with other methods that together enhance the lethal effect of heat on microorganisms and result in a lowering of the intensity of conventional heat treatments. This approach has lately revived the interest of scientists in what has become known as the 'preservation of foods by combined processes'.

Although the preservation of foods by combined processes is not new, the advance of scientific knowledge has opened new possibilities: the influence of different microenvironmental parameters on the heat resistance of micro-organisms is now much better known and new lethal effects of some physical phenomena have been reported. For example, the combination of heat and reduced pH to lower microbial heat resistance allowed the use of milder heat treatments and was one of the first combined processes to be employed. Other combinations widely used are those with sodium chloride, nitrite, etc. More recently, technological advances have led to the investigation of other possible combinations: These include the combination of heat with ultrahigh pressures, which attracted the interest of many research groups world-wide (Gould. 1973)

and, most recently, the combination of heat with antimicrobial preservatives like organic acids. The antimicrobial activity of these acids is well-documented (Doores, 1983). Cell walls, cell membranes, metabolic enzymes, protein synthesis system and genetic material are the main targets of their action against a wide range of microorganisms.

With respect to the improvement of techniques for the inactivation of microorganisms in foods, most effort and new application has concerned thermal processing. A particular aim has been to minimise damage to product quality. This is being pursued in two, often complementary, ways. Firstly, by the wider application of more high temperature-short time processing, with associated aseptic packaging where relevant. Secondly, by delivering heat in new ways, e.g. by microwaves or by electrical resistance ("ohmic") heating of foods, which allow better control of heat delivery and minimize the over-cooking that commonly occurs in more conventional thermal processes.

2.7.1 HEAT INACTIVATION OF MICROORGANISMS

Inactivation of microorganisms by heat is a fundamental operation in food preservation (Toledo, 1993). Although Nicholas Appert first performed the preservation of foods by heat in France around 1810, this remained for a long time an empirical practice until the scientific knowledge on the mechanism of the preservation effect began to accumulate. The works of Bigelow (1921) finally established the sound basis on which, still today, current methods of heat preservation rely.

The observation by Bigelow that the death of microorganisms followed a first order reaction kinetic pattern was essential for the future development of th technology of food preservation by heat. Bigelow showed that every unit of

heating time of a microbial population at a given temperature reduced the number of viable cells by a constant proportion. By plotting the log of the number of survivors as a function of heating times, a straight line is therefore obtained. In this plot (survival curve), the minutes needed to reduce the number of viable cells to 1/10 (one log cycle) of its original value is now known as the 'decimal reduction time', or D_t value. When log D_t values are plotted vs. their corresponding heating temperatures (Decimal Reduction Time Curve; DRTC), again a straight line is obtained. The number of degrees Celsius of temperature increase for the log D_t value to decrease by one log cycle is known as z value. The heat resistance of microorganisms is defined by these two parameters. Once a D_t value is known, the kinetics of death (Survival curve) allows prediction of the numbers of survivors after a given heating time. Furthermore, as z value allow the calculation of the lethal effect of each temperature, the total lethal effect of any given process, including heating and cooling phases, can be estimated, thus avoiding undue overprocessing.

Work carried out by food microbiologists on the influence of different factors on heat resistance of micro-organisms and on the kinetics of death, has led to some authors to question the validity of some published heat resistance data and that of the Bigelow's kinetics. It appears that heat resistance data (D_t and z values), once considered as well defined and constant parameters are in fact very variable, being influenced by many factors. For example, the pH of heating menstruum is one of the most important and one of the firsts to be known. But many others, such as the water activity (a_w) (Alderton *et al.*, 1980); sporulation temperature (Beaman and Gerhardt, 1986; Condon *et al.*, 1992b) and growth medium (Donnelly and Busta, 1980), composition of heating medium

(Blocher and Busta, 1983; Condon and Sala, 1991) and incubation temperature and medium after heat treatment (Cook and Gilbert, 1968; Feeherry *et al.*, 1987) have also been investigated. Some heat resistance data reported in literature should therefore be accepted with caution as factors influencing these data were unknown to the authors or not taken into account. The effect of some influencing factors can be so big as to make the differences in heat resistance between two populations of the same strain, bigger than those between two unrelated species (Put and Aalbersberg, 1967). The capacity of different parameters to strongly influence the heat resistance of micro-organisms is currently an important issue in thermobacteriology, as are the deviations from theoretical death rate kinetics, such as those reported by some authors on survival curves and DRTC. Among different deviations reported on the patterns of survival curves (Moats *et al.*, 1971; Brown and Ayres, 1975), 'tails' and 'shoulders' are the most frequent and best characterised. A combination of both can explain most, if not all deviations of linearity of survival curves.

'Tails' are end portions of survival curves that appear with a decreasing slope at the final stages of heating. A comprehensive review of the 'tail' phenomenon is that of Cerf (1977). The different hypotheses to explain this phenomenon have been classified by Cerf into two groups of theories: 'vitalistic' and 'mechanistic'. 'Vitalistic theories' try to explain deviations from linearity of survival curves by postulating a different heat resistance for each individual cell in a population. 'Mechanistic theories' assume a logarithmic death rate and blame the appearance of deviations to methodological artefacts (Stumbo, 1973) or to the development of a higher heat resistance during heat treatments (Mackey and Derrick, 1986a). The development of a higher heat resistance of

vegetative cells during heat treatments, reported by different authors, would be due to metabolic changes (Mackey and Derrick, 1986b) or to interactions with the heating menstruum. Although the fraction of the population having a higher heat resistance is normally very small, its heat resistance can be so high that it can become the factor determining the intensity of heat treatments (Moats *et al.*, 1971; Condon *et al*, 1992a). Current concern to reduce the intensity of heat treatments in order to improve the quality of food products has led to a more detailed study of death rate kinetics and to model heat treatments in such a way as to take into account deviations of logarithmic death rate (Cole *et al.*, 1993).

'Shoulders', appear in the first portion of the survival curves, with different shapes. In 'shoulders' the slope of survival curves is always smaller and sometimes the number of survivors not only does not decrease, but also can even increase. This phenomenon is less frequent in vegetative cells and some authors have related it to cell clumps desegregation (Hansen and Riemann, 1963). 'Shoulders' are much more frequent in spore suspensions. In som authors' opinions (Shull *et al.*, 1963; Lewis *et al.*, 1965), in spores, 'shoulders' are often caused by a lack of 'activation'. A high proportion of a spore population is often unable to germinate. The spores are in a latent ('dormant') state. Some chemical/physical treatments can 'activate' them, restoring their germination capacity. Heat is a well-known activation agent. During the first moments of a heat treatment two opposite phenomena therefore take place, each at a different rate and both catalyzed by heat: the activation of 'dormant spores' and the concurrent and subsequent inactivation of all spores. It is now believed that activation follows, as does heat inactivation, first-order reaction kinetics

(Abraham *et al.*, 1990; Sapru *et al.*, 1993). The balance between both rate constants would determine the profile of 'shoulders'.

In the last 35 years, attempts have been made to develop mathematical models of death rates that would include 'shoulders'. Shull *et al.* (1963), in his attempt to develop the first model, postulated that activation and heat inactivation were two separate and successive phenomena. Other authors (Abraham et al., 1990) who also postulated that activation is in fact the limiting factor of the inactivation phenomenon also shared this opinion. On the contrary, other authors (Rodriguez *et al.*, 1991; Sapru *et al.*, 1992) believed that both phenomena are simultaneous and a prior 'activation' is not necessary for spores to be inactivated by heat. There is no agreement about whether the heat resistance of activated and dormant spores is the same. While some have developed mathematical models assuming equal heat resistance (Rodriguez *et al.*, 1991), the models of others assume that they are different (Sapru *et al.*, 1993).

Other deviations of linearity of death kinetics in DRTC have also been reported. However, these are less known and there is no agreement among authors. While some investigators have reported that *z* values increase at higher temperatures of treatment (DRTC curves bend upwards) (Wang *et al.*, 1964; David and Merson *et al.*, 1990) others have reported that they decrease (Cerf and Hermier, 1973; Hermier *et al.*, 1975). In some authors' opinion (Cerf and Hermier, 1973) the decrease of D_t values at high temperatures of treatment could be due to a thermal shock that would be greater the higher the temperature of treatment, causing the DRTC to bend downwards (decreasing *z* values). According to these authors the higher D_t and *z* values at higher temperatures

reported in literature would be explained by methodological errors. Difficulties in the measurement of the very short heating times involve in high temperature treatments would result in poor estimations of heating times. Much therefore remains uncertain about heat resistance and death kinetics.

Despite substantial efforts carried out during the last half of this century, the mechanism(s) of heat inactivation are not yet clear. According to the first interpretation, the strict logarithmic order of death, as postulated by Bigelow, could most easily be explained by a mechanism involving the destruction of one single or a small number of vital molecules per cell. As the kinetics of cell death have become better known many authors have attempted to explain deviations from linearity by implying in these mechanism different vital molecules and/or structures. Heat has been reported to damage different cell structures, including damage to cell membranes, ribosome, DNA, RNA and enzymes. DNA is still considered the most likely lethal target molecule, but damage occurring at the same time in different molecules and/or structures may also result in heat inactivation. Some of these injuries can be repaired and ultimately it is the balance of intensity of injury/capacity to repair that determines cell viability. A more detailed review of the mechanisms of microbial heat inactivation and injury is that of Gould (1989).

2.7.2 PHYSICS OF HEAT TRANSFER

When heat is exchanged between matter, or parts of the same matter, it is called heat transfer. Heat transfer always occurs from warm to cool. It is generally transferred by one, or a combination, of three processes: conduction, convection and radiation (Lawton and Klingenberg, 1996)

Conduction: If heat is applied directly to one part of a solid object, the electrons become excited. This causes molecular collisions, which travel along the object, heating as it passes through. This transfer of heat within a solid is known as conduction and the ability to transfer heat within an object is called thermal conductivity. It varies for different materials. Gold, silver and copper have high thermal conductivity. These materials are also good conductors of electricity. Other materials, such as glass and mineral wool, have low thermal conductivity. This quality makes them good insulators.

Convection: Conduction between objects, where one is a gas or liquid, is called convection. As gasses or liquids are heated, the excited molecules achieve a fluid motion. Where gravity is a factor, such as here on earth, the natural fluid motion moves the heated, less dense molecules up and the cooler, more compact molecules down. The fluid motion of the gas or liquid molecules may also be forced by a current of air, for example.

Radiation: The transmission of energy across space is called radiation. Radiation does not depend on the presence of matter and can occur across a vacuum. Radiant heat transfer generally involves the range of electromagnetic waves called infrared radiation. All matter releases radiant energy. Hotter matter releases more radiant energy than cooler matter.

Infrared radiation (IR) : IR energy is emitted by all materials above 0°K (Toledo, 1993). Infrared radiation is part of the Electromagnetic Spectrum and occupies frequencies between visible light and radio waves. The IR part of the spectrum spans wavelengths from 0.7 micrometers to 1000 micrometers (microns). Within this wave band, only frequencies of 0.7 microns to 20 microns are used for practical, everyday temperature measurement. This is because the IR detectors

currently available to industry are not sensitive enough to detect the very small amounts of energy available at wavelengths beyond 20 microns (Siegel and Howell, 1992).

Though IR radiation is not visible to the human eye, it is helpful to imagine it as being visible when dealing with the principles of measurement and when considering applications, because in many respects it behaves in the same way as visible light. IR energy travels in straight lines from the source and can be reflected and absorbed by material surfaces in its path. In the case of most solid objects which are opaque to the human eye, part of the IR energy striking the object's surface will be absorbed and part will be reflected. Of the energy absorbed by the object, a proportion will be re-emitted and part will be reflected internally. This will also apply to materials which are transparent to the eye, such as glass, gases and thin, clear plastics, but in addition, some of the IR energy will also pass through the object. These phenomena collectively contribute to what is referred to as the *Emissivity* of the object or material (Sala, 1986).

Materials which do not reflect or transmit any IR energy are known as blackbodies and are not known to exist naturally. However, for the purpose of theoretical calculation, a true blackbody is given a value of 1.0. The closest approximation to a blackbody emissivity of 1.0, which can be achieved in real life is an IR opaque, spherical cavity with a small tubular entry. The inner surface of such a sphere will have an emissivity of 0.998. Different kinds of materials and gases have different emissivities, and will therefore emit IR at different intensities for a given temperature. The emissivity of a material or gas is a function of its molecular structure and surface characteristics. It is not generally a function of color unless the source of the color is a radically different substance to the main

body of material. A practical example of this is metallic paints which incorporate significant amounts of aluminum. Most paints have the same emissivity irrespective of color, but aluminum has a very different emissivity which will therefore modify the emissivity of metallized paints. (Hottel and Sarofim, 1967).

Just as is the case with visible light, the more highly polished some surfaces are, the more IR energy the surface will reflect. The surface characteristics of a material will therefore also influence its emissivity. In temperature measurement this is most significant in the case of infrared opaque materials which have an inherently low emissivity. Thus a highly polished piece of stainless steel will have a much lower emissivity than the same piece with a rough, machined surface. This is because the grooves created by the machining prevent as much of the IR energy from being reflected.

The laws upon which infrared temperature measurement is based are old, established and well proven (Lawton and Klingenberg, 1996). These are as follows:

1. *Kirchoff's Law* (1860) : When an object is at thermal equilibrium, the amount of absorption will equal the amount of emission.

2. *Stephan Boltzmann Law* (1879) : The hotter an object becomes the more infrared energy it emits.

3. *Wien's Displacement Law* (1896) : The wavelength at which the maximum amount of energy is emitted becomes shorter as the temperature increases.

4. *Planck's Equation* (1900) : Describes the relationship between spectral emissivity, temperature and radiant energy.

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CHAPTER 3

INACTIVATION OF MICROFLORA ON WHOLE BROILER CARCASSES BY RADIANT HEAT AND ANTIMICROBIAL ADDITIVES[1]

[1]Islam, M. M., and Toledo, R. T. To be submitted to the Journal of Food Science.

ABSTRACT

The capability of radiant heat to reduce resident microflora on whole broilers was investigated. Whole ready-to-cook broilers were exposed to a radiant wall (RW) at 649 °C, for 0, 3, 4, 5, or 8 s or dipped in a solution containing 1% buffered sodium citrate, pH 5.8 (BSC), 0.5% citric acid (CA) or 2% liquid smoke (LS) prior to RW exposure. Radiant heating in an air (RW/A) or superheated steam atmosphere (RW/S) was also tested. RW/S treatment for 5 s reduced total plate count (TPC) by 1.23 to 1.73 log. RW exposure for 3 and 4 s showed less than a log reduction. RW exposure for 8 s resulted in 2.12 to 2.41 log reduction of TPC however, product exhibited a cooked skin. TPC reduction was not significantly different with RW/A and RW/S treatments but skin in RW/A treatments appeared to be dehydrated. Dipping in 1% BSC was synergistic with RW in reducing the TPC but CA and LS pre-treatments had no effect. Orientation during RW treatment showed no significant differences on TPC. The inside body cavity of treated carcasses was not affected by the RW treatment

KEY WORDS: Poultry, microorganisms, pasteurization, radiant heat, sodium citrate, antimicrobials

INTRODUCTION

In 1992, the U.S. poultry industry produced $ 12 billion worth of birds at the farm level, which were processed into products valued at $32 billion (Durham, 1993). In 1993, over 27.6 billion pounds of ready-to-eat poultry products were produced (Agricultural Statistics Board, USDA, 1994). The widespread sale and use of raw chicken demands closer attention to their microbiology. Chilled or frozen, chicken may be marketed as whole, whole cut-up, bone-in parts or deboned. With few exceptions, bacterial growth is a surface phenomenon in raw poultry products. The quality of the chicken meat is considered optimum immediately after processing, and maintenance of acceptable quality depends on initial microbial levels and measures taken to minimize the growth of organisms. The surface micro flora of ready-to-eat chicken carcasses is heterogeneous, consisting of mesophilic and psychrotrophic bacteria from the animal itself, soil and water bacteria from the environment, and bacterial species introduced by man and equipment during processing (Grau, 1986; ICMSF,1980). Populations of bacteria on surfaces of raw chicken carcasses at the end of processing vary, but typically the range is from 10^3 to 10^5 aerobic mesophillic organisms per inch^2 (ICMSF, 1980). Because the post-processing environment is frequently refrigerated, a low-level contamination with psychrotrophic bacteria almost always occurs. The two major concerns are control of spoilage organisms which cause consumers to reject the product due to unacceptable odor or flavor, and minimization of pathogenic organisms which may, under prolonged storage or faulty handling, lead to a health hazard (Cunningham, 1987). When chicken is held under refrigeration, the micro flora begins to shift toward psychrotrophs of the *Pseudomonas-Acinetobacter-*

Moraxella group (Barnes, 1976). Earlier studies by Barnes and Impey (1969) found that the organisms most commonly found growing on poultry carcasses at low temperatures (around 1°C) were pigmented and non-pigmented species of *Pseudomonas*, *Pseudomonas putrifaciens*, and strains of *Acinetobacter*. These authors also noted that *P. putrifaciens* grew much faster on leg muscle than on breast, and explained this on the basis of a difference in pH - leg muscle having pH 6.4 - 6.7, and breast 5.7 - 5.9. In an earlier report (Ayres 1959), it was stated that the microbial population responsible for spoilage of the refrigerated product (4°C) was psychrotrophic. After 12 days storage, the dominant psychrotrophic population was 90% *Pseudomonas-Achromobacter*. Pseudomonads were the most significant Gram negative rods associated with spoilage of poultry.

Poultry processors must minimize microbial counts in processed birds to prolong shelf life as well as reduce the incidence of pathogenic microorganisms. Generally, practices used to reduce microbial counts would also reduce pathogenic microorganisms. It was hypothesized that very rapid surface heating for a short time would effectively reduce the number of microorganisms on the surface while maintaining the normal raw appearance of the product. Surface decontamination may be useful because pathogenic microorganisms are usually only on the broiler surface (Gill and Penney, 1977). Generally, microbial inactivation requires less energy than cooking (Harper, 1976), therefore, radiant heat of adequate intensity to only heat the surface would be effective for this purpose. High intensity radiant heat application was tested using a Radiant Wall Oven (RWO). The system consists of a cylindrical steel alloy (91 cm long by 45.7 cm internal diameter) enclosed by a larger cylinder which is insulated on the outside. A jet gas burner forces combustion gases in the annular space between

the cylinders generating intense heat to raise the temperature of the inside cylinder sufficiently high to make the surface an intense radiant heat source. The oven controls the surface temperature of the radiant wall, this being the only true manifestation of the radiant heat transfer. When steam is introduced into the radiant wall, the high temperature converts saturated steam rapidly into superheated steam. Thus, heating may be done in an atmosphere of saturated steam (RW/S) or if the steam is not used, an air atmosphere surrounds the sample (RW/A).

The objective of this study were: to define the heating parameters for decontamination of whole dressed broilers additives without producing a cooked appearance on the surface using radiant heat and to investigate the synergy of the thermal treatment and various antimicrobial additives on inactivation of indigenous microorganisms on the chicken skin.

MATERIALS & METHODS

Whole broiler chickens

Forty whole broiler carcasses in each of three replicate trials (120 total) were obtained directly from the chiller exit of a commercial broiler processing plant. These carcasses were processed from 7 - 8 weeks old birds and semi-scalded at 60°C for 90 s. The broiler carcasses were transported in ice to the laboratory where they were placed in a walk-in cooler at 0.5°C and treated within 2 h.

Radiant energy source

A radiant wall (RW) oven (Model 12-36, Pyramid Food Processing Equipment Manufacturing, Tewksbury, MA) was used. Samples were exposed to

the radiant wall while travelling on a wire conveyor belt through the central axis of the heated cylinder. A special rack was constructed to permit the carcasses to ride the conveyor vertically with the vent cavity positioned downwards. Most carcasses entered the RW with the breast forward. To determine if the orientation had an effect, a set of samples were treated with entering the RW oven with the back forward. The carcasses were surrounded by the radiant wall, thus all surfaces received equal exposure to the radiant heat. The linear speed of the conveyor belt was adjusted to achieve a desired dwell time in the radiant zone.

Antimicrobial agents

Buffered sodium citrate, pH 5.8 (BSC) is a USDA approved ingredient for meats provided by WTI , Inc (Highland, NY). Food grade citric acid (CA) was obtained from Greenfield-Thorpe Corp. (Chicago IL). Liquid smoke (LS) was a specially formulated wood smoke fraction designated "Code V" (Hickory Specialties, Brentwood, TN). Aqueous solutions of these materials were prepared and placed in a 4-liter stainless steel beaker to permit complete immersion of a whole carcass in the solution. The solution was replaced with each carcass . Solutions were 1% BSC, 0.5% CA w/w or 2% LS (v/v). These materials have been found in our preliminary work to have some antimicrobial effects.

Treatments : Whole carcasses were taken directly from the cold room and either introduced directly into the RW oven or dipped in the antimicrobial solution at ambient temperature (24 - 27°C) for 1 min. followed by RW exposure. Following the RW treatment, each carcass was removed from the conveyor and placed in a sterile Stomacher bag (Seward Medical, UK), overwrapped with a 1-mil

polyethylene bag and stored in the walk-in cooler at 0.5°C until analyzed. RW temperature was maintained at 649°C for all treatments. Exposure time was 3, 4, 5, or 8 s and the atmosphere was either air or superheated steam. The experimental design (replicate x time of RW exposure x no. of dip treatments and RW atmosphere) was 3 x 5 x 8. The 8 dip RW atmosphere treatments were as follows: No dip steam RW atmosphere (RW/S/0); No dip air RW atmosphere (RW/A/0); BSC dip steam RW atmosphere (RW/S/BSC) ; BSC dip air RW atmosphere (RW/A/BSC); CA dip steam RW atmosphere (RW/S/CA), CA dip air RW atmosphere (RW/A/CA; LS dip steam RW atmosphere (RW/S/LS) and LS dip air RW atmosphere (RW/A/LS). One carcass was used for each of 3 replicates for a total of 120 carcasses treated.

Sampling and CFU enumeration : Carcasses were visually evaluated by the authors after RW exposure for discoloration caused by burning, cooking or interaction by heat and the pre-dip solutions. Samples exhibiting changes in appearance from the raw carcasses were considered unacceptable treatments. Following microbiological sampling, the carcasses were baked and the cooked product evaluated for off-flavors from the dip and RW treatments. Colony forming units (CFU) were enumerated on chicken skin by excising aseptically about 2.5 g (1 sq. inch of skin) each from 3 different areas (breast, back and vent) of each carcass. The excised tissue was placed in a Stomacher bag (Seward Medical, London) containing 97.5 ml of sterile 0.1% bacto peptone solution (Difco Laboratories, Detroit, MI) and pummeled for 60 s in a Model 400 Stomacher (Seward Medical, London). Serial dilutions were made with sterile 0.1 % bacto-peptone. A 2.5 g tissue sample was scrapped from the middle of the inside carcass cavity and similarly prepared for microbial evaluation. The Total Plate

Count (TPC) procedure described by Swanson et al. (1992) was used. Pour plates were made using standard Plate Count Agar (Difco Laboratories) and plates were incubated at 32°C for 24 - 48 h. Colony forming units (CFU) were counted using a Quebec dark field colony counter (American Optical Company, Buffalo, NY).

Statistical analyses :Microbiological data were transformed into logarithms of the number of colony-forming units/cm2 (log_{10}/cm2). Average data and standard errors were calculated from three replications. The analysis of variance (ANOVA) procedure was used to detect significance of replications, exposure times, dip treatments, orientation of chicken and different atmospheres. Comparisons of means were based on Duncan's multiple range test. All values reported as significant were analyzed at the $\alpha = 0.05$ level.

RESULTS AND DISCUSSION

Effect of treatment time :The efficacy of the different treatments in decontaminating fresh chicken broilers is presented in Table 1. As expected, increased reduction of surface microorganisms resulted with increasing treatment time. However, although samples treated for 8 sec, consistently reduced surface flora by at least 2 log, visual evaluation of the samples showed a cooked appearance. On the other hand, treatment times of 3 and 4 s failed to consistently reduce TPC by 1 log. Broilers dipped in 1% BSC solution before RW exposure for 3 or 4 sec without steam showed more than 1 log reduction in TPC. The result is due to combined effects of the antimicrobial agent and radiant heat. RW exposure for 5 s consistently resulted in 1.26 to 1.73 log TPC reduction. At the time of experiment, the RW burner was inadequate to heat the

RW to a higher temperature and thus, the effects of a more intense radiant heat treatment could not be evaluated at this time. We hypothesiged that a higher RW temperature will achieve greater TPC reduction with shorter treatment time and not induce visible change in product appearance.

Effect of steam : A superheated steam atmosphere in the RW oven did not affect TPC reduction on RW exposure. Microbial log reductions on samples treated in an air atmosphere were not significantly different from log reductions on samples treated in a superheated steam atmosphere, as shown in Fig.1. Steam was expected to modulate the harshness of dry radiant heat on the delicate chicken skin to avoid burning at any given spot. We observed that when steam was used, the broiler skin appeared moist and fresh after RW exposure. However, as indicated in the graph, a steam atmosphere reduced slightly the radiant heat effect on the microorganisms probably because of the lower transmittance of the radiant energy through steam compared to air. Although using steam or air atmosphere had no significant effect on TPC reduction, use of a steam atmosphere in the RW oven is still desirable because of a better appearance of the treated carcasses in a steam atmosphere.

Effect of anti-microbial agents : TPC and log reduction data for various pre-treatments by anti-microbial preservatives are presented in Table 1. At the concentrations of the 3 anti-microbial agents used, only a slight synergistic effect on TPC reduction over RW treatment alone was observed. While BSC dip improved the reduction by about half a log, both citric acid and liquid smoke treatments improved it only by a quarter log. In an earlier experiment we determined that retention of BSC by chicken dipped in BSC solution is only approximately 1% of the solution concentration. Thus, a 1% BSC solution would

permit retention of only a 0.01% BSC on the chicken surface. Thus, higher concentrations than 1% BSC could possibly be used to get a better synergistic effect on microbial decontamination.

Effect of carcass position : Table 2 shows that there was no significant difference in total reduction of microorganisms due to orientation of carcasses. There was also, no significant difference in log counts of microorganisms inside the body cavity of chicken carcasses before and after the radiant heat treatment (Table 3). This indicates that the radiant heat did not reach the inside body cavity of the carcasses and could not bring any reduction of TPC.

CONCLUSION

Radiant heat from a high temperatrure radiant wall induced microbicidal effects on surfaces of whole broilers without cooking the surface. Radiant wall exposure for 5 s at 649 °C with a 1 min predip in 1 % buffered sodium citrate solution induced more than 1.5 log reduction in TPC.

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TABLE 1: Mean ± standard error of log numbers of aerobic bacteria on the surface of fresh broilers variously treated and exposed to radiant heat for different periods of time

Treatments[c]	Mean ± SE[a] log_{10} CFU/cm^2 at various exposure time (sec) to RW[b]				
	0	3	4	5	8
RW/S/0	3.80 ± 0.19	3.14 ± 0.12	2.92 ± 0.43	2.54 ± 0.41	1.53 ± 0.26
RW/A/0	3.80 ± 0.16	2.91 ± 0.14	2.82 ± 0.32	2.51 ± 0.31	1.51 ± 0.11
RW/S/BSC	3.28 ± 0.16	2.87 ± 0.20	2.53 ± 0.09	2.11 ± 0.43	1.38 ± 0.23
RW/A/BSC	3.28 ± 0.23	2.76 ± 0.18	2.47 ± 0.11	2.05 ± 0.13	1.42 ± 0.18
RW/S/CA	3.51 ± 0.07	3.16 ± 0.37	3.04 ± 0.24	2.28 ± 0.21	1.39 ± 0.11
RW/A/CA	3.51 ± 0.13	3.12 ± 0.22	3.03 ± 0.09	2.23 ± 0.23	1.34 ± 0.25
RW/A/LS	3.50 ± 0.22	3.05 ± 0.15	2.67 ± 0.17	2.26 ± 0.13	1.38 ± 0.23
RW/S/LS	3.50 ± 0.13	3.04 ± 0.12	2.60 ± 0.14	2.24 ± 0.15	1.33 ± 0.12

[a] Data represent the average of three broiler carcasses (n = 3) and standard error ranged from ± 0.07 for low and ±0.43 for high

[b] All radiant heat treatments were at 649 °C

[c] Treatments were

RW/S/0 : No dip, steam RW atmosphere
RW/A/0 : No dip, air RW atmosphere
RW/S/BSC : 1% Buffered Sodium Citrate dip, steam RW atmosphere
RW/A/BSC : 1% Buffered Sodium Citrate dip, air RW atmosphere
RW/S/CA : 0.5% Citric acid dip, steam RW atmosphere
RW/A/CA : 0.5% Citric acid dip, air RW atmosphere
RW/S/LS : 2% Liquid smoke dip, steam RW atmosphere
RW/A/LS : 2% Liquid smoke dip, air RW atmosphere

TABLE 2: Effect of positional orientation of chicken carcass on the surface microbial reduction when treated in a Radiant wall oven at 649 °C for 5 sec in a steam atmosphere

Treatment	TPC ($Log_{10}CFU/cm^2$)		Log reduction
	Before treatment	After treatment	
Breast forward	3.78 ± 0.14	2.05 ± 0.11	1.73 ± 0.03[a]
Back forward	3.81 ± 0.09	2.10 ± 0.17	1.71 ± 0.08[a]

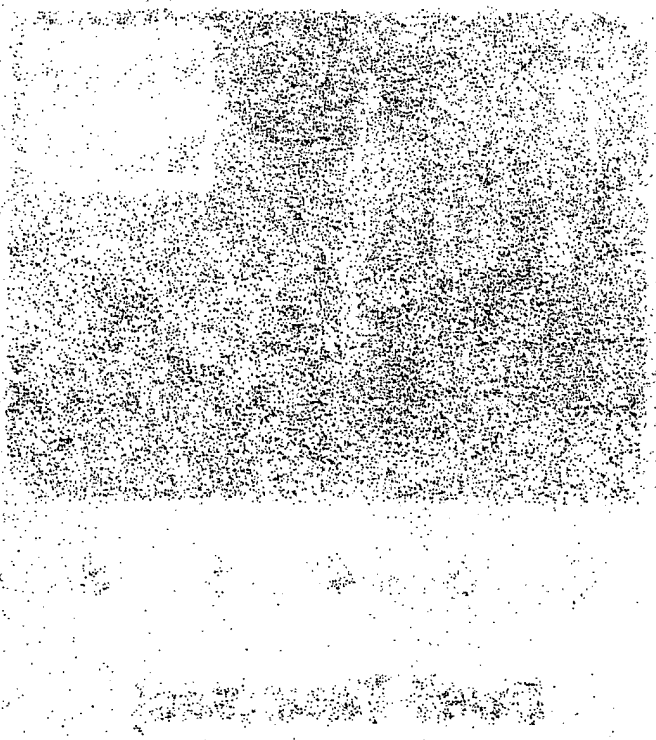
[a] Data represent average of three broiler carcasses (n=3). Means within columns with common following letter are insignificant ($P< 0.05$).

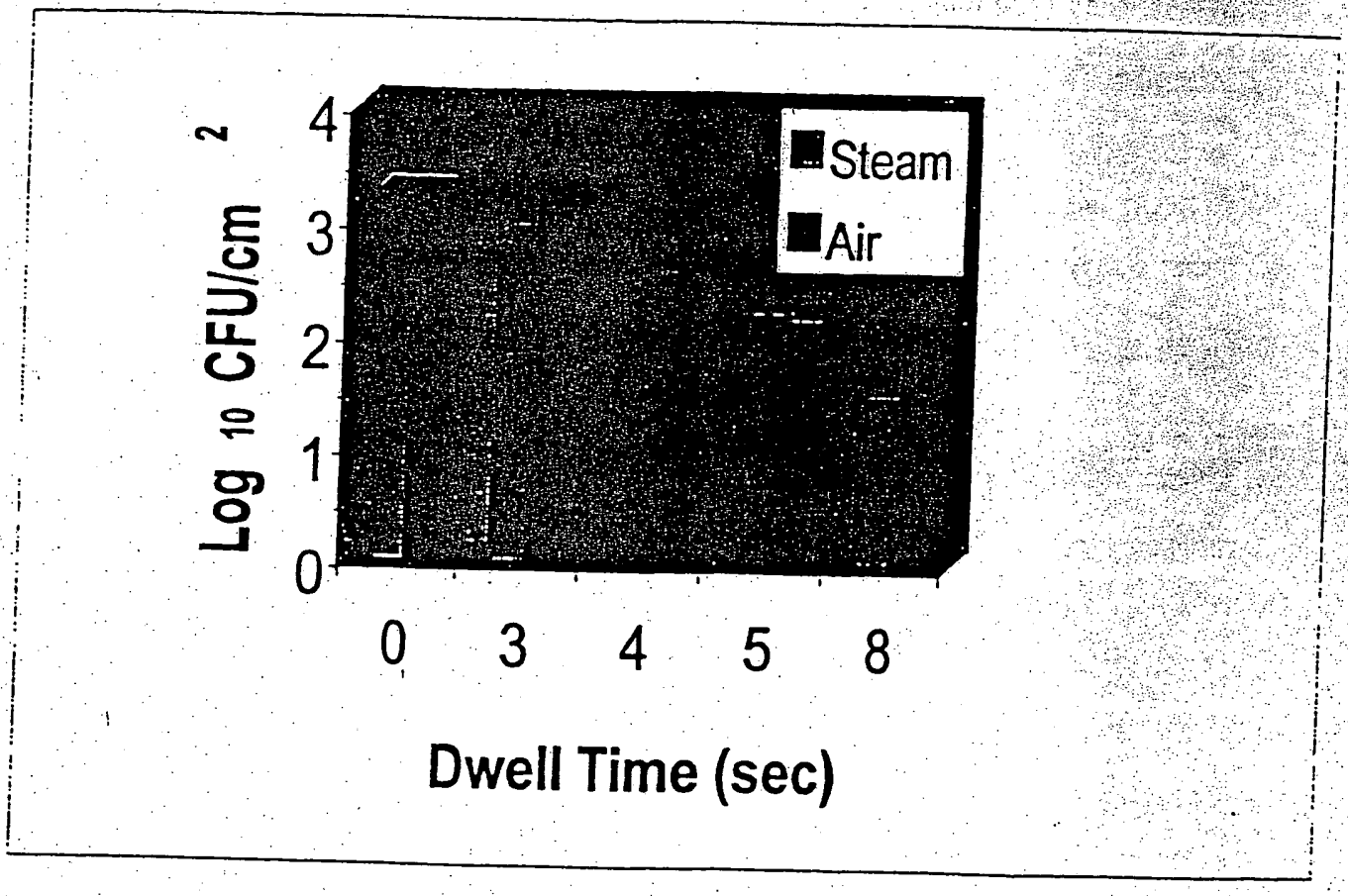
TABLE 3 : Effect of radiant heat on the microorganisms inside the body cavity of broiler carcasses when exposed to a radiant wall at 649 °C for 5 sec in a steam atmosphere with or without buffered citric acid (BSC)

Treatments	TPC($Log_{10}CFU/cm^2$)		Log reduction
	Before treatment	After treatment	
RW	4.13 ± 0.21	4.07 ± 0.22	0.06 ± 0.01[a]
BSC/RW	3.53 ± 0.18	3.49 ± 0.16	0.04 ± 0.02[a]

[a] Data represent average of three broiler carcasses (n=3). Means within columns with common following letter are insignificant ($P< 0.05$).

FIGURE 1. Effect of radiant heat environment on the destruction of surface microorganism on chicken surface exposed for various periods of time to a radiant wall at 649 °C for 5 sec in a steam atmosphere




Log 10 CFU/cm 2
4
3
2
1
0
Steam
Air
0
3
4
5
8
Dwell Time (sec)

CHAPTER 4

EFFECT OF RAPID SURFACE HEATING OF BROILER PARTS BY RADIANT ENERGY ON MICROBIAL QUALITY AND SHELF LIFE

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[1]Islam, M. M., Toledo R. T., and Fletcher, D. L. To be submitted to the Journal of Food Science.

ABSTRACT

Radiant energy and buffered (pH 5.8) sodium citrate (BSC) were used to inactivate surface microorganisms on raw chicken drumsticks. Total plate counts were evaluated during storage at 0°C and 4°C. Drumsticks were dipped in BSC (0 to 10%) and exposed 3 s to a radiant wall (RW) at 788°C. Optimum BSC dip was 6%; lower levels induced less microbial reduction and higher levels gave poor product flavor. Maximum $\log_{10}$ reduction in total surface microflora was 2 to 3, providing a shelf life to 27 d at 0°C vs. 13 d for controls or 18 d for RW treatment only. At 4°C, shelf life of BSC/RW treated drumsticks was 21 d vs. 10 d for control and 13 d for RW only treatment. Immediate chilling after RW treatment with dry ice snow prior to packaging and storage had no effect on shelf life. Skin modification by different scald procedures affected shelf life; semi-scald (52°C) shelf life at 0°C was 29 d vs. 23 d for sub-scald (60°C).

KEY WORDS: Chicken drumsticks, shelf life, radiant wall, buffered sodium citrate, scalding, microbial quality

INTRODUCTION

Thirty six billion pounds of broiler chicken meat were processed in the United States in 1996 (USDA, 1998). Approximately 80% of this meat was sold fresh (unfrozen). Extension of shelf life is a primary concern of the industry. Fresh poultry shelf life depends on the number of spoilage bacteria on the product immediately after processing and post processing hold temperature. Spoilage is manifested by high levels of psychrotrophic bacteria (Russell, 1997). Normal healthy broilers carry extensive microbial contamination on their feathers, skin and intestinal tract (ICMSF, 1980; Cunnigham, 1982; Cunningham and Cox, 1987). During hanging and bleeding operations, wing flapping generates aerosols which may distribute contamination to the defeathered carcasses (Sofos, 1994). In addition, the moist and warm equipment in the processing line spreads contamination among carcasses (Grau, 1986). In general, contamination occurs during all processing steps including stunning, bleeding, scalding, defeathering, washing, evisceration, and washing and chilling in ice water or in cold air (Mead, 1982). Due to the rapid rate of processing, which reaches more than 6000 birds/h on some lines, contact with processing equipment favor the spread of microorganisms. Certain processing practices make control of microbial contamination more difficult with poultry (Mead, 1989). It is traditional for the carcass to remain whole throughout the process, thus making it difficult to remove the intestines without breakage through a relatively small opening in the abdomen. The need to retain the skin provides a complex surface, which is especially conducive to the entrapment of bacteria because of the numerous pores present following feather removal (Thomas and McMeekin, 1980). After evisceration and final wash, carcasses are immersion

chilled in a communal ice bath. Although rapid chilling reduces bacterial growth the process also results in cross contamination of carcasses (Lillard, 1982). The most common spoilage bacteria of refrigerated poultry are *Pseudomonas*, *Acinetobacter*, and *Lactobacillus* (Elliott et al., 1995). *Pseudomonas* spp. becomes the predominant organisms on the surface of spoiled poultry. Populations of bacteria on surfaces of raw poultry carcasses at the end of processing vary, but typically the range is from 10^3 to 10^5 aerobic mesophilic organisms per cm^2 (ICMSF, 1980). Since bulk chicken drumsticks must be obtained from several birds and are subjected to considerably more handling than are intact poultry carcasses, they may contain greater indigenous micro flora than other higher value parts of the chicken. Many bacteria adhere firmly to poultry carcasses during processing (McMeekin and Thomas, 1978). Several approaches have been suggested to reduce the level of microbial contamination on poultry during processing and storage. The application of chlorine (Villareal et al., 1990), organic acid (Lillard et al., 1987) or sorbate (Robach, 1979) dips has been used to sanitize meat and poultry carcasses. This approach requires relatively long treatment times (2-120 min) and typically only small reductions (≤ 1 log cycles) in bacterial count have been achieved. Also, these dips had a serious detriment on the appearance and sensory quality of the products. Ultrasonic energy (Sams and Feria, 1991) and ultraviolet radiation (Stermer et al., 1987) treatments have also been considered, but were ineffective for products with irregularly shaped surfaces. Ionizing radiation is effective in decontaminating poultry carcasses (Mulder et al., 1977) but its application may be hindered by cost and current consumer resistance. Modified atmosphere packaging to extend shelf life of fresh poultry has proven to have some merit, (Finne, 1982) however, there is

a big risk of growth of any facultatively anaerobic or anaerobic psychrotrophic pathogens. Other potential non-thermal methods to extend shelf life such as, Pulsed Electric Fields (PEF) and Pulsed High-intensity Light (PHIL) technology (Yousef, 1996), High Hydrostatic Pressure (HHP) Raffalli et al., 1994), Bacteriocins (Shefet et al., 1995; Crosby, 1998) etc. have been tried with limited success. Flash steam heating followed by evaporative cooling (Morgan, et al., 1996, Cygnarowicz-Provost, 1994) was reported to be effective in some cases. But, this method is not yet fully developed nor commercially applied. As no other method of food preservation to replace heat has yet been developed, we investigated a new approach of applying heat to the product. We hypothesize that radiant energy of adequate intensity will rapidly heat a surface to kill microorganisms while rapid dissipation of this heat will prevent development of a cooked appearance. In addition, rapid surface heating also evaporates moisture from the surface concentrating any applied antimicrobial agent on that surface prior to the radiant heat exposure. In a previous work (Islam and Toledo, 1989) we demonstrated the effectiveness of radiant energy as an antimicrobial treatment for exposed surfaces of raw poultry. Since the interior cavity of whole dressed broilers could not receive the radiant energy, it was concluded that the treatment would be more effective for cut-up parts since all surfaces can be exposed to the radiant energy. The objectives of this study were: to investigate microbicidal effects of surface application of buffered sodium citrate, pH 5.8, and radiant energy from a high temperature radiant wall on microorganisms on broiler parts; and to determine if the type of skin surface resulting from different scalding treatments has an influence on the microbicidal effects of the treatment.

MATERIALS AND METHODS

Radiant energy source

Radiant energy was obtained from a RW oven (Model 12-36, Pyramid Food Processing Equipment Manufacturing, Tewksbury, MA). The oven was previously described by Islam and Toledo (1998). The manufacturer improved the unit used in the present work to provide a higher burner capacity thus allowing the RW temperature to be maintained at 788°C.

Antimicrobial agent

Based on previous studies by Islam and Toledo (1998), buffered sodium citrate (BSC), pH 5.8 was used. BSC was obtained from WTI Inc., Highland, NY). Various concentrations of this solution (w/v) were prepared by mixing appropriate quantities of powdered BCS to corresponding appropriate quantities of deionized water.

Broiler parts

For our first experiment, broiler drumsticks were obtained from a local processing plant. The drumsticks were mechanically severed from carcasses within 1 h of exit from the chiller. The drumsticks were then, packed in ice, and transferred to the laboratory and treated within 1 h.

For our second experiment, drumsticks were also obtained from broilers processed in the pilot processing facility of the Department of Poultry Science, University of Georgia, Athens, to evaluate the effects of scald treatments on inactivation of surface microorganisms by radiant energy. Forty live chickens (6 to 7 weeks old) were divided into two groups of 20 birds each. Each group of birds was hand slaughtered and scalded either at 52°C (semi-scald, 125°F) to leave the epidermis intact or 60°C (sub-scald, 140°F) to remove the epidermis. The scalding

time was 90 s and picking time was 45 s in a rotary batch picker. Each group of the chicken carcasses was chilled in a static ice and water slush separately for 30 min. After draining for 30 s drumsticks from each carcass were removed by hand and brought to the Food Processing Laboratory in ice chest. Samples were treated within 2 h.

Treatments

Effect of BSC concentration in 1-min dip: In this first part of the first experiment, 11 concentrations of BSC, and 3 s of exposure to the RW at 788°C were used. Microbicidal effects were evaluated as log reduction of the natural micro flora and changes in CFU during storage at 0 and 4°C. The experimental design was 11 x 2 x 2 (BSC concentration in dip x storage temperature x 2 replicates) for a total of 44 data sets. Ten drumsticks were used per data set (440 total drumsticks from the commercial plant) and 10 untreated drumsticks were saved as control per replicate and storage at each of the two storage temperatures (40 controls). For each replicate of a dip treatment, 20 drumsticks were dipped 1 min in BSC solutions (0 to 10% in 1% increments) then placed on a wire mesh screen to drain for 30 s. Drumsticks were then individually exposed to radiant heat. The treated drumsticks were caught from the conveyor as they emerged from the RW oven directly into sterile Stomacher pouches (Seward Medical, London). Equal numbers (10 each) of these individually bagged drumsticks were stored at 0°C and 4°C

Verification of optimum dip and RW exposure and effect of rapid chilling after RW exposure: In the second part of the first experiment, 100 drumsticks from the commercial plant (10 per treatment) were treated as follows:

Description	Designation
6% BSC dip, RW exposed, no post chill	RW/BSC
6% BSC dip, RW exposed, post chilled	RW/BSC/PC
no dip, RW exposed, no post chill	RW
no dip, RW exposed, post chilled	RW/PC
no dip, no RW, no post chill	CONTROL

Treated samples were stored at 0 and 4°C. All RW exposure was at 788°C for 3 sec. When a dip was used, all 10 drumsticks per treatment were immersed in the 6% BSC solution and drained before RW exposure as described above. Post-chill was conducted to remove residual heat from the RW exposed drumsticks prior to storage. This was achieved by applying dry ice snow on the drumsticks before sealing the stomacher bags in which they were stored.

Effect of skin condition induced by scald temperature on antimicrobial effects of radiant energy: Chicken drumsticks used for the second experiment were processed in the pilot processing plant as described earlier. Twelve drumsticks were used per treatment. After treatment, each drumstick was individually bagged as previously described and stored at 0°C. The following treatments were performed:

Description	Designation
Semi-scald, no dip, no RW exposure	A
Semi-scald, no dip, RW exposed	A1
Semi-scald, 6% BSC dip, RW exposed	A2
Sub-scald, no dip, no RW exposure	B
Sub-scald, no dip, RW exposed	B1
Sub-scald, 6% BSC dip, RW exposed	B2

Sampling and enumeration:

Drumsticks from the commercial plant. Immediately following treatment and after 2, 5, 10, 13, 18, 21, 23, 25, and 27 d of storage at 0°C and 4°C, one drumstick from each treatment was removed for evaluation and TPC enumeration. All samples were evaluated subjectively by at least two laboratory workers for odor and appearance upon opening of the bag in which they were stored. Each sample in a sterile Stomacher bag was weighed. Approximate amounts of 0.1% sterile peptone was added to each sample to give a ratio of 1.0 ml of peptone to 1.0 cm^2 of sample surface area according to Goresline and Haugh (1959). The samples were prepared by shaking the bag vigorously 50 times in 1 ft arcs at approximately 3 shakes/sec. Total plate counts (TPC) were made on the appropriate decimal dilution of the samples in sterile 0.1% peptone by standard pour plate method using plate count agar (Difco, Detroit, MI). Duplicate plates were made on all samples and incubated for 24 h at 32°C. This time and temperature of incubation were found to allow rapid growth of the bacterial colonies without causing the colonies to touch, leading to erroneous results in counting (Elliot, et al., 1995). Both plates at a dilution giving 30 to 300 CFU/plate following incubation were counted using a Quebec dark field colony counter Model 3330 (American Optical Company, Buffalo, NY) and average of the two plates were reported.

Drumsticks from the pilot plant. In the second experiment, the samples from the controlled scalding processes were analyzed by the skin excision and maceration technique. Immediately following treatment (day 0) and after 2, 5, 10, 13, 18, 21, 23, 25, 27 and 29 d of 0°C storage, one drumstick from each treatment was sampled for microbial enumeration. The two samples (a 1 sq. inch skin samples aseptically removed from the middle area of a drumstick and the whole drumstick)

were then analyzed separately by the two following methods: skin maceration and the whole drumstick rinse. In the skin maceration technique, each skin piece was homogenized with 100 ml of sterilized 0.1% peptone water in a Stomacher 400 lab blender (Seward Medical, London) for 60 sec. Dilutions of the homogenate were made with sterilized peptone water (0.1%). Total plate counts (cfu/ml of rinse water) were made in duplicate pour plates using plate count agar (Difco, Detroit, MI) with plate incubation at 32°C for 24 hours. The surface area of each drumstick was calculated from its weight using the formula: Surface Area (cm^2) = 85.6 +[1.41 x wt. (g)] (Goresline and Haugh 1959). Results were recorded as CFU/cm^2 of skin surface.

For the whole drumstick rinse method, same procedure for microbial enumeration was followed as described in the first experiment.

RESULTS AND DISCUSSION

Effect of BSC concentration in the pre-dip

Increasing concentrations of BSC in the dip resulted in lower viable organisms in the treated samples immediately after treatment (Table 1). Untreated controls showed log (CFU)/ml of rinse of 4 which compares with data from Islam and Toledo (1998) of log (CFU)/cm^2 of 3.3 to 3.8 in whole broiler carcasses. Log reduction with 1% BSC dip and 3 s exposure to RW at 788°C (Table 1) was 1.9 compared to 1.2 previously reported by Toledo and Islam (1988) with 1% BSC dip and 5 s exposure to RW at 648°C. The higher RW temperature induced more inactivation with the same dip and exposure time. Increasing dip concentration increased the log reduction to a full 4 log cycle reduction with a BSC dip concentration of 8% or higher. As expected, higher

initial counts before storage resulted in faster increase of TPC and for the same treatment, a higher storage temperature resulted in higher growth rate of spoilage organisms (Table 2).

The effectiveness of the combinations of BSC dip and RW exposure on storage life of the drumsticks is shown in Figs.1 (A and B) for storage at 0 and 4 °C, respectively. The useful shelf life is defied as the time at which the total bacteria count reached 10^7/ml. This limiting TPC is used since it generally correlates with the onset of detectable off-odor of spoilage. This was observed in the odor of samples evaluated before microbial evaluation in the present study. Other studies (Robach, 1979) also used this microbiological criteria for spoilage of poultry. There was a 5-day difference in reaching 10^7/ml between 0% BSC dip and RW exposed samples compared to control samples at both 0°C and 4°C storage. BSC dip up to 3% with RW exposure did not improve shelf life over controls at 4°C, while dip of 4% and 5% BSC extended the shelf life 10 days above those of controls. Dipping in BSC without RW exposure did not significantly increase the shelf life compared to control samples. A dip in 6% BSC added 11 days to the shelf life of poultry over control samples even at 4°C storage. The shelf life was double that of control samples. Similar results are shown for storage at 0°C. Controls spoiled at 12 d at 0°C compared to 10 d at 4°C. However, the difference in shelf life between controls and treated samples at both storage temperatures were similar. Slime and putrid off-odors were noticed on control drums as early as 10 days at 4°C and the average counts had risen above 10^7 per ml and spoilage was clearly evident in the smell of all control drumsticks at this point in storage. In contrast, RW treated chicken drumsticks had average counts below 10^7 until 18 d storage at 4°C while those

treated with RW and 6% BSC had shelf life up to 21 d. Similarly, signs of spoilage did not appear until 21 d in RW treated samples stored at 0°C while the control spoiled in 13 d. RW treated drumsticks predipped in 6 % BSC had shelf life of 27 d at 0°C. Although dipping in BSC concentrations greater than 6% showed higher log reduction just after RW treatment, there appears to be no difference in the shelf life compared to those dipped in 6% (Figs. 1 A and B). Thus, the optimum BSC concentration for the dip appears to be 6%.

Verification of optimum dip and effects of rapid chilling following RW exposure: Figs. 2(A and B), shows results of 6% BSC pre-dip, RW exposure and rapid chilling post RW exposure on log reduction and microbial proliferation during storage. As expected, the highest shelf life of 27 d (Fig. 2A) for the RW/BSC and RW/BSC/PC treated drumsticks stored at 0°C. This verifies previous results for the same treatments (Fig. 1A). The influence of quick chilling by dry ice post-RW treatment was not evident. The curves for the microbial population with storage time were very similar with or without post-chill. Results for the 4°C stored samples of the same treatments (Fig. 2B) follow the same trend as for those at 0°C. While the control sample at 4°C had spoiled by 10 days, the RW/PC samples spoiled at 13 d and RW/BSC/PC samples were spoiled in 21 days. Post chilling did not enhance the shelf life. (Table 3).

Effect of skin condition as influenced by scald temperature: Prior to scalding and mechanical defeathering, the skin surface is rough and folded, with thin cornified cells in various stages of exfoliation (Connor, et al, 1987). The stratum corneum and stratum germinativum which constitute the epidermis are separated from underlying dermal tissue by a basal lamina (Matoltsy, 1969). After a sub-scald process (60°C), the entire epidermis is removed during defeathering and the

exposed dermal tissue provides a new surface for colonization by microorganisms (Thomas and McMeekin, 1980). Semi-scald (52°C), by comparison, do not facilitate removal of the epidermis. After scald/defeatheimg treatments, the skin surface retains a film of processing water, which invariably contains insoluble and soluble organic matter plus large numbers of bacteria (Thomas and McMeekin, 1980). This film of water, which appears to play a central role in contamination, is initially derived from the scald tank and water applied during defeathering which usually is water reused from processes downstream such as chiller water overflow. Obviously, the lethal effect of water held at 60°C (sub-scald) would be considerably greater than that at 52°C (semi-scald). We observed 0.6 log less microorganisms on sub-scalded compared to semi-scalded drumsticks enumerated by the rinse method (Table 4). However, the difference was not observed in skin maceration method. The difference is due to the recovery method for surface microorganisms, since there would be no expected difference in actual numbers. The film of water that contains most of the organisms on the surface originates from the water used to chill the carcass. The small difference in TPC between the sub- and semi-scalded drumstick would have no effect on the shelf life in subsequent storage if no further treatments were applied. However, with BSC dip followed by RW treatments, there was a significant difference on the microbiological load of the sub-scalded and semi-scalded drumsticks and the changes in numbers during storage. Figs. 3(A and B) show the TPC of semi-scalded as well as sub-scalded chicken drumsticks enumerated by rinse and skin maceration methods respectively. Interestingly, BSC dipped and RW treated drumsticks that were sub-scalded had a shelf life of only 23 d compared to 29 d for semi-scalded drumsticks. Similarly, only RW treated sub-scalded drumsticks had a

shelf life of 21 d compared to 25 d for semi-scalded drumsticks. But when we compare the control samples, sub-scalded drumsticks had a shelf life of 18 d vs. 13 d for semi-scalded drumsticks. Radiant heat appears to be less destructive to microorganisms on the sub-scalded skin surface. It could be due to the fact that during scalding removal or damage of the epidermal layer exposes a new surface for contamination, which is smoother and less hydrophobic, but is deeply channeled. Microorganisms firmly attached to these channels are less likely to be affected by the radiant heat. This is further confirmed by the fact that consistently higher TPC were obtained by the skin maceration method compared to rinse method for similarly treated sub-scalded drumsticks. A number of studies, including that of Avens and Miller (1970) and Lillard (1983) showed that skin excision plus blending resulted in higher bacterial recovery than those obtained by the rinse method. Bacteria, which can not be rinsed off, have been considered firmly attached to meat or skin surfaces. It has been assumed that blending and stomaching results in as complete a recovery of attached bacteria as possible, whereas the rinse or swab method does not necessarily recover all bacteria on poultry tissue (Notermans and Kampelmacher, 1975).

CONCLUSION

Assuming proper refrigeration is maintained during distribution and retail, RW treatment results in improved microbiological quality and potentially greater shelf life and safety for raw poultry parts. Adding a 6% BSC solution dip before RW exposure greatly increased the shelf life. Rapid chilling of RW treated chicken drumsticks was ineffective on microbial quality. The epidermis on the chicken skin plays a vital role on the keeping quality. In general, when

epidermis is left on the skin, the shelf life of RW treated drumsticks was increased due to better exposure of microorganisms to radiant heat facilitating their destruction.

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TABLE 1 :*Total bacterial populations (log_{10} CFU/ml) recovered from chicken drumsticks dipped in various buffered sodium citrate solutions for 1 min, exposed to a radiant wall at 788°C for 3 s and held for 0, 3, 5, 10, 13, 18, 21, 23, 25, or 27 d at 0°C.*

Treatment BSC/RW	Mean[A] log_{10} CFUs per ml of surface rinse									
	Day 0	Day 3	Day 5	Day 10	Day 13	Day 18	Day 21	Day 23	Day 25	Day 27
0 %	2.5	2.7	3.4	4.5	5.5	*7.0* [B]	NT	NT	NT	NT
1 %	2.1	2.5	3.3	4.3	5.3	*7.3* [B]	NT	NT	NT	NT
2 %	2.0	2.4	3.1	4.1	5.0	6.1	*7.3* [B]	NT	NT	NT
3 %	2.1	2.3	3.0	3.9	4.5	4.9	*7.0* [B]	NT	NT	NT
4 %	2.0	2.1	2.9	3.6	4.0	4.3	6.1	*7.1* [B]	NT	NT
5 %	1.4	1.9	2.5	3.1	3.9	4.2	5.5	6.7	*7.0* [B]	NT
6 %	1.2	1.5	2.1	2.9	3.2	3.9	4.6	5.8	6.5	*7.1* [B]
7 %	1.0	1.3	2.0	2.8	3.3	4.0	4.6	5.6	6.3	*7.0* [B]
8 %	ND	1.1	1.9	2.6	3.1	4.1	4.5	5.3	6.1	*7.1*
9 %	ND	1.0	1.7	2.7	3.1	4.0	4.5	5.2	6.0	*7.1*
10 %	ND	ND	1.4	2.3	2.9	3.8	4.2	5.0	5.8	*7.0*
Control	4.0	4.7	5.1	5.8	*7.0*	NT	NT	NT	NT	NT

[A] – Number of observations per mean n = 6
[B] – Italicized numbers indicate that spoilage levels have been reached
NT- not tested
ND- not detected

TABLE 2 :*Total bacterial populations (log_{10} CFU/ml) recovered from chicken drumsticks dipped in various buffered sodium citrate solutions for 1 min, exposed to a radiant wall at 788°C for 3 s and held for 0, 3, 5, 10, 13, 18, 21, 23, 25, or 27 d at 4°C.*

Treatment BSC/RW	Mean[A] log_{10} CFUs per ml of surface rinse									
	Day 0	Day 3	Day 5	Day 10	Day 13	Day 18	Day 21	Day 23	Day 25	Day 27
0 %	2.5	3.2	5.0	6.3	*7.0*[B]	NT	NT	NT	NT	NT
1 %	2.1	3.2	4.9	6.1	*7.1*[B]	NT	NT	NT	NT	NT
2 %	2.0	3.0	4.7	6.0	*7.0*[B]	NT	NT	NT	NT	NT
3 %	2.1	3.2	4.5	5.9	*7.0*[B]	NT	NT	NT	NT	NT
4 %	2.0	3.1	4.3	5.2	6.3	*7.4*[B]	NT	NT	NT	NT
5 %	1.4	3.0	4.2	5.0	6.1	*7.1*[B]	NT	NT	NT	NT
6 %	1.2	2.5	3.7	4.6	5.1	6.3	*7.0*[B]	NT	NT	NT
7 %	1.0	2.5	3.5	4.4	5.0	6.1	*7.0*[B]	NT	NT	NT
8 %	ND	2.4	3.3	4.5	5.3	6.4	*7.0*[B]	NT	NT	NT
9 %	ND	2.0	3.0	4.2	5.0	6.1	6.8	*7.4*[B]	NT	NT
10 %	ND	2.0	2.9	4.0	4.9	5.4	6.5	6.9	*7.2*[B]	NT
Control	4.0	5.2	6.6	*7.8*[B]	NT	NT	NT	NT	NT	NT

[A] – Number of observations per mean n = 6.
[B] – Italicized numbers indicate that spoilage levels have been reached
NT- not tested
ND- not detected

TABLE 3 : *Effect of post-radiant heat rapid chilling on the shelf life of chicken drumsticks exposed to a radiant wall at 788°C for 3 s and stored at 0 and 4°C.*

Treatment	Shelf life (days)	
	Chilling	No Chilling
0 ° C		
Control	NT	13
RW	18	18
BSC/RW	27	27
4 ° C		
Control	NT	10
RW	13	13
BSC/RW	21	21

NT- not tested

RW- treated only by radiant heat

BSC/RW - dipped in 6% buffered sodium citrate for 1 min and exposed to RW

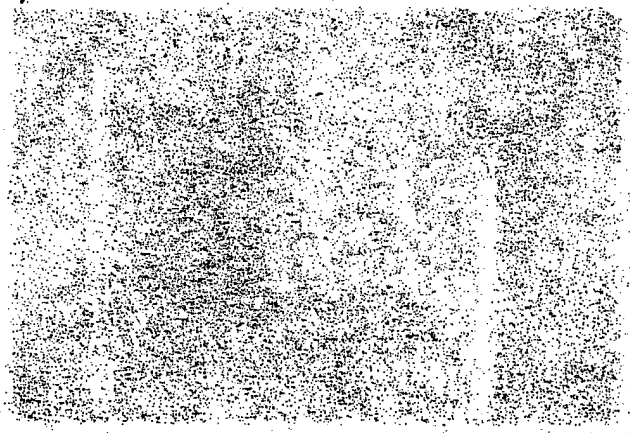
TABLE 4 : *Total bacterial populations (log_{10} CFU/cm^2 ± SE) recovered by whole drumstick rinse method and skin maceration method from chicken drumsticks processed at two different scalding temperatures (52 and 60°C) and exposed to a radiant wall (RW) at 788°C with or without a predip in 6% buffered sodium citrate (BSC) solution.*

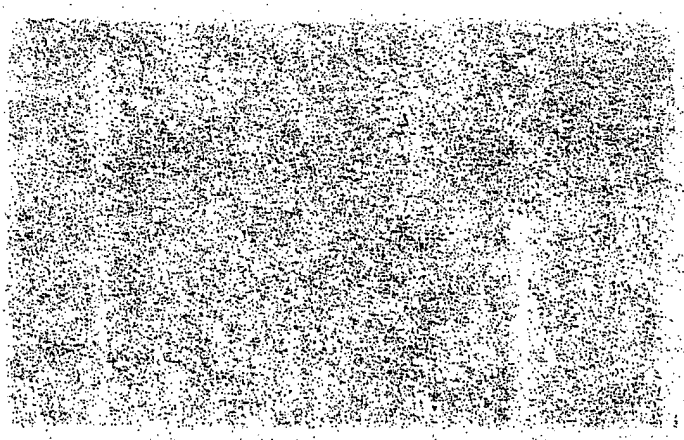
Samples[a]	TPC[b] Rinse Method		TPC[b] Maceration method	
	Log CFU/cm^2	Log Reduction	Log CFU/cm^2	Log reduction
A	4.3 ±0.1	-	3.8 ±0.1	-
A1	1.6 ±0.2	2.7 ±0.3^A	1.8 ±0.1	2.0 ±0.2^B
A2	1.4 ±0.1	2.9 ±0.2^A	1.3 ±0.2	2.5 ±0.3^C
B	3.7 ±0.2	-	3.9 ±0.1	-
B1	1.9 ±0.3	1.8 ±0.5^B	2.4 ±0.1	1.5 ±0.2^D
B2	1.7 ±0.2	2.0 ±0.4^B	1.7 ±0.1	2.2 ±0.2^E

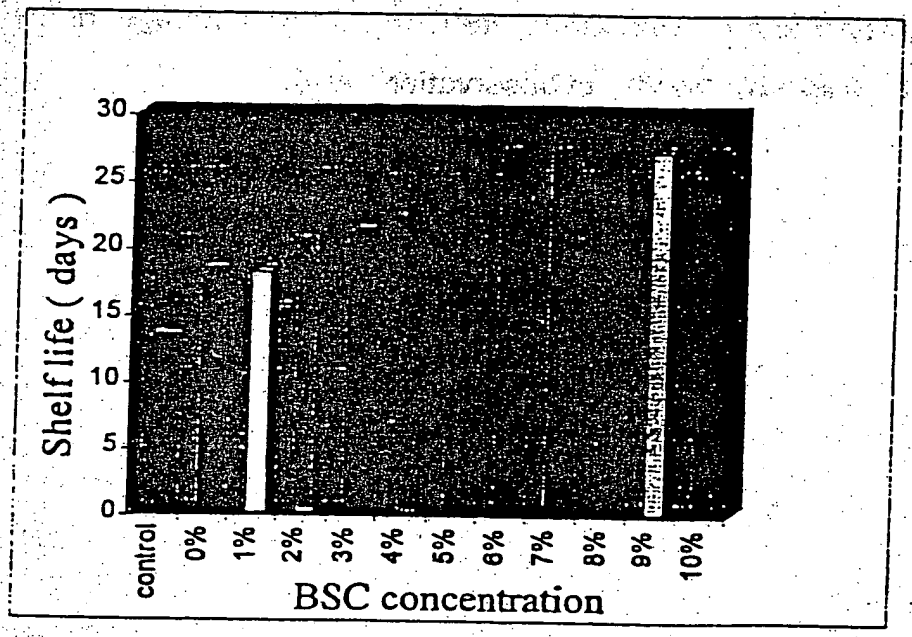
[a] Samples are:
A - semi-scald (52°C) , control
A1 - semi-scald, treated only by radiant heat
A2 - semi-scald, 1-min dip in BSC and then treated by radiant heat
B - sub-scald (60°C) , control
B1 - sub-scald, treated only by radiant heat
B2 - sub-scald, 1-min dip in BSC and then treated by radiant heat

[b] Mean ± SE. Means within columns followed by the same letters are not significantly different ($P < 0.05$). $n = 6$

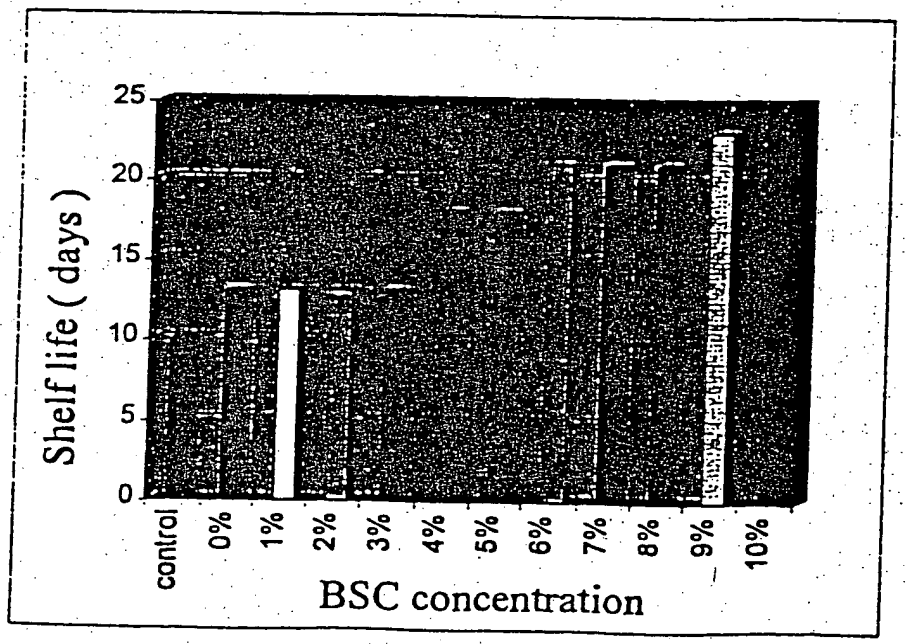
FIGURE 1 : Effect of dipping for 1 min in various concentrations of buffered sodium citrate (BSC) solution on the shelf life of chicken drumsticks prior to exposure to a radiant wall at 788°C for 3 s and storage at 0°C (Graph A) and at 4°C (Graph B). Number of observations n=6.





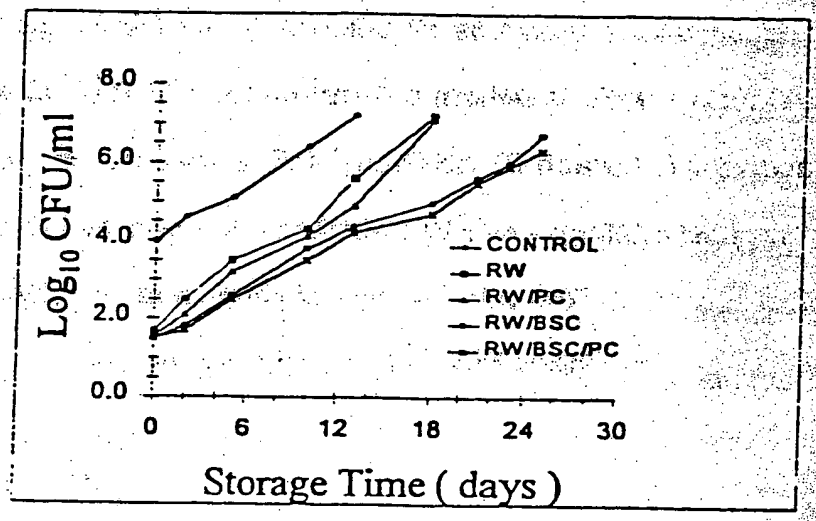

Shelf life (days)
30
25
20
15
10
5
0
control
0%
1%
2%
3%
4%
5%
6%
7%
8%
9%
10%
BSC concentration

A

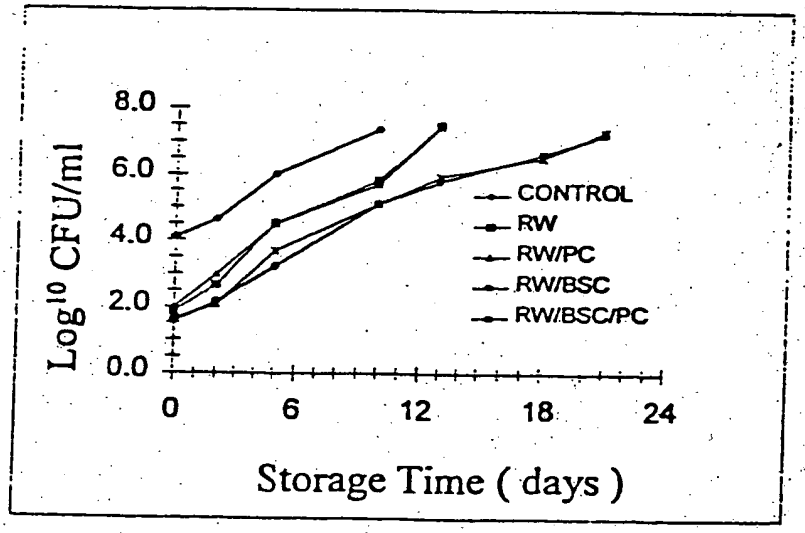

Shelf life (days)
25
20
15
10
5
0
control
0%
1%
2%
3%
4%
5%
6%
7%
8%
9%
10%
BSC concentration

B

FIGURE 2 : Effect of post-radiant heat rapid chilling on the growth characteristics of surface microorganisms of chicken drumsticks exposed to a radiant wall at 788°C for 3 s with or without a 1-min dip in 6 % BSC and storage at 0°C (Graph A) and at 4°C (Graph B). Various treatments are : -◆- control; -■- RW treatment with no post-chilling; -▲- RW treatment followed by rapid post-chilling; -●- dip in BSC followed by RW with no post-chilling; and -✳- dip in BSC followed by RW with rapid post-chilling. Number of observations n=6.

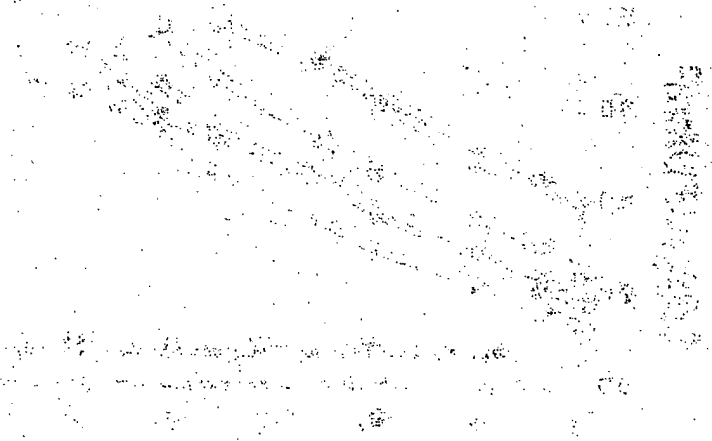

8.0
6.0
4.0
2.0
0.0
Log10 CFU/ml
0
6
12
18
24
30
Storage Time (days)
CONTROL
RW
RW/PC
RW/BSC
RW/BSC/PC

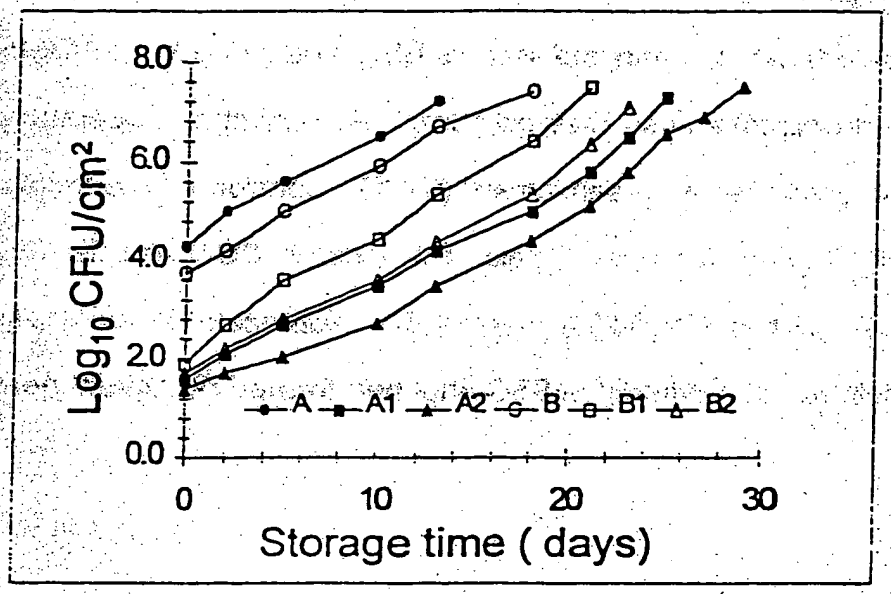
A


8.0
6.0
4.0
2.0
0.0
Log10 CFU/ml
0
6
12
18
24
Storage Time (days)
CONTROL
RW
RW/PC
RW/BSC
RW/BSC/PC

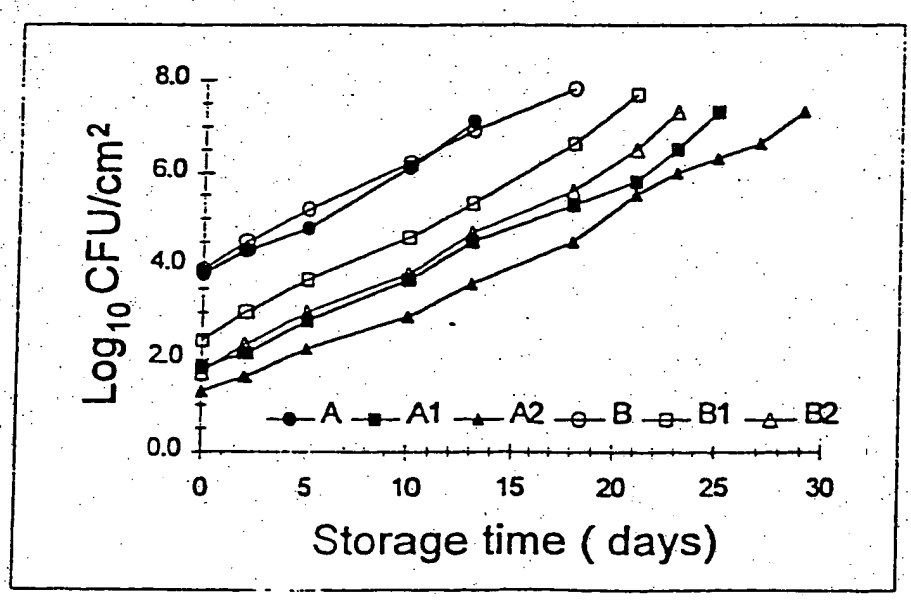
B

FIGURE 3 : Effect scalding temperatures on the growth characteristics of surface microorganisms of chicken drumsticks exposed to a radiant wall at 788°C for 3 s with or without a 1-min dip in 6 % BSC and stored at 0°C as enumerated by whole drumsticks rinse method (Graph A) and skin maceration method (Graph B). Samples are: A - semi-scald (52°C) , control; A1 - semi-scald, treated only by radiant heat; A2 - semi-scald, 1-min dip in BSC and then treated by radiant heat; B - sub-scald (60°C) , control; B1 - sub-scald, treated only by radiant heat; B2 - sub-scald, 1-min dip in BSC and then treated by radiant heat.




8.0
6.0
4.0
2.0
0.0
Log10 CFU/cm2
A
A1
A2
B
B1
B2
0
10
20
30
Storage time (days)

A


8.0
6.0
4.0
2.0
0.0
Log10 CFU/cm2
A
A1
A2
B
B1
B2
0
5
10
15
20
25
30
Storage time (days)

B

CHAPTER 5

REDUCTION OF *SALMONELLA* AND *CAMPYLOBACTER* ON FRESH CHICKEN DRUMSTICKS BY TREATMENT IN A RADIANT WALL OVEN

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[1]Islam, M. M., and Toledo, R. T. To be submitted to the Journal of Food Science.

ABSTRACT

No viable CFU of a nalidixic acid-resistant *Salmonella typhimurium* (*S. typhimurium* ^{NAR})were recovered from chicken drumsticks inoculated with 100 CFU and exposed 3 s to a radiant wall (RW) at 788°C. There was no recovery from heat injury after 3 d of refrigerated storage at 4°C. However, viable CFU was detected when 1,000 CFU was inoculated and exposed to RW only. The 1,000 CFU inoculum showed no CFU recovery when drumsticks were dipped in a 6% solution of buffered sodium citrate, pH 5.8 (BSC) prior to RW exposure. No viable CFU of *Campylobacter jejuni* were detected on raw chicken drumsticks inoculated with 1,000 CFU and exposed to RW. Viable CFU was recovered from a 10,000 CFU inoculum. Challenge studies with large inoculum of each pathogen gave log reductions of 0.79, 1.73 and 2.32 for *S. typhimurium*^{NAR} on fresh chicken drumsticks treated respectively with only BSC, only RW and combined BSC/RW. Similar treatments on *Campylobacter jejuni* yielded 1.45, 2.41, and 3.36 log reduction respectively.

KEYWORDS : *Salmonella*, *Campylobacter*, poultry, radiant heat, buffered sodium citrate, pasteurization,

INTRODUCTION

Increased consumption of poultry products in the USA has resulted in increases in food borne illnesses associated with poultry. Pathogenic bacteria associated with poultry include: *Salmonella* spp. (Bryan, 1980), *Listeria monocytogenes* (Brackett, 1988), *Staphylococcus aureus* (Bergdoll, 1989), and *Campylobacter jejuni* (Stern, et al., 1985). Among these microorganisms, *Salmonella* spp. and *Campylobacter* spp. are responsible for most poultry food-transmitted illnesses (Mulder and Bolder, 1984). Poultry associated diseases are major burdens on society causing considerable suffering and loss of productivity, and adds to the cost of food production and health care (Bryan and Doyle, 1994). Among diseases acquired by ingesting undercooked or recontaminated poultry, salmonellosis and campylobacteriosis are of primary contemporary concern in the United States. Risks of acquiring these diseases are greatly influenced by the prevalence of *Salmonella* spp. and *C. jejuni* in fowl and subsequently in poultry products. Dubert (1988) estimated that 35 % of chicken carcasses in the United States are contaminated with *Salmonella*, and an average of 62 % by *C. jejuni* (Bryan and Doyle, 1994). Proper handling and cooking can adequately eliminate most risk from these pathogens on poultry (Thayer, et al., 1992). Consumer complaints and publicity have increased the need for higher standards of bacterial quality in poultry products (Shane, 1988). Federal and State governments and poultry Industry representatives are interested in reducing numbers of pathogens on poultry to reduce risk of food borne illnesses (Sams and Feria, 1991).

The relatively high incidence of these diseases will continue unless some means is devised and implemented that will either eliminate these bacteria from poultry or drastically reduce their contamination (Bryan & Doyle, 1994). During processing even in sanitary modern processing plants, salmonellae and campylobacters are present on poultry throughout the processing steps. Scalding, defeathering, evisceration and giblet harvesting operations are the major points of transfer of microorganisms. Many studies have shown that *Salmonella* spp. and *Campylobacter* spp. attached to poultry carcasses can survive immersion in 52 to 60 °C scald water (Kim et al., 1993; Morrison and Fleet, 1985; Slavik et al., 1994). These pathogens can subsequently spread to non-contaminated carcasses during defeathering and chilling (Clouser et al. 1995; Clouser et al. 1995b). Often, greater numbers of processed carcasses and parts become contaminated than there are infected or contaminated live animals coming to slaughter. Unless poultry is heat processed or given another treatment to kill pathogens, additional removal, prevention and control procedures are needed to reduce the risk of poultry borne disease. There is an immediate need for a cost-effective approach to reduce the prevalence of *Salmonella* spp. and *C. jejuni* on poultry. Costs for effective measures that will reduce, prevent or eliminate these pathogens should be substantially lower than the estimated costs to society due to poultry-related human diseases. Moreover, these measures can encourage more poultry products consumption by reducing the consumer's concern about the safety of poultry.

A number of control points for salmonellae and campylobacters are available to the broiler industry during live production, including use of salmonella-free feed, bio-security, and dust and vector control (Jones, et al, 1990). However, the ultimate control points are in the slaughtering and dressing operations , which has been the primary target in the implementation of the Hazard Analysis Critical Control Point (HACCP) program (Tompkin, 1990). Elimination of gram-negative food borne pathogens, including *Salmonella* spp. and *Campylobacter* spp. at the production level is currently not feasible. Therefore, an intervention step to substantially reduce or eliminate them during processing is desperately needed to ensure the safety of raw animal products.

With respect to techniques for the inactivation of micro organisms in foods, the most widely accepted has been thermal processing. A desired outcome of a heat treatment is elimination of pathogens with minimal damage to product quality. This is being pursued in two, often complementary, ways. Firstly by the application of high temperature-short time processing and protectively packaging the treated carcasses to prevent recontamination. Secondly, by delivering heat in new ways. Very rapid surface heating for a short time is thought to be an effective method in reducing salmonellae and campylobacters on the surface of the chicken. To achieve this we used radiant energy from a high temperature radiant wall (RW), to raise the surface temperature to levels lethal to bacteria within a very short time and combining this treatment with an antimicrobial dip. Reduction or elimination of these pathogens on poultry

carcasses before the retail product reaches the consumer should reduce the risk of food borne salmonellosis and campylobacteriosis.

The purpose of this study was to evaluate the effects of RW exposure with or without a pre-dip in buffered sodium citrate, pH 5.8, on the survival of *S. typhimurium*^{NAR} *and C. jejuni* inoculated on the skin of chicken drumsticks.

MATERIAL AND METHODS

Chicken drumsticks

Tray-packed chicken drumsticks were obtained from the fresh meat display case of a local supermarket 1-2 h before the treatments. The brand name of the product was noted and subsequent purchases for later experiments were of the same brand. All tray packs of the drumsticks used were stamped with a "sell by" date which was at least 10 days later than the date of purchase. Drumsticks were used directly on removal from the tray pack. Enough drumsticks were purchased at one time to conduct 3 treatments at 5 levels of inoculation of one organism. Each treatment and inoculum level consisted of 10 drumsticks.

Treatments

Drumsticks were inoculated individually with either of two gram negative pathogenic bacteria *Salmonella typhimurium or Campylobacter jejuni*. Inoculum levels were 0, 10, 100, 1,000 and 10,000 cells. When an anti-microbial dip treatment was used, the drumsticks were dipped first in the solution, allowed to drain for one minute before they were inoculated. The following treatments were

used: Control ; 3 s exposure to RW at 778 °C (RW); dipped in a 6% solution of buffered sodium citrate, pH 5.8 (BSC) with no subsequent treatment; and ; pre-dipped in BSC followed by RW exposure (BSC/RW).

Test organisms

Salmonella typhimurium: A nalidixic acid-resistant strain of *Salmonella typhimurium* (*S. typhimurium*^{NAR}) obtained from the culture collection of Dr. Mark Harrison, Food Science and Technology Department, University of Georgia, Athens, was used. This organism's resistance to 200 ppm nalidixic acid was used to verify that the recovered CFUs were from the inoculum. An 18 h actively growing culture (mid-log phase of growth) on Brain Heart Infusion (BHI) agar (Difco Laboratories, Detroit, MI) slants at 37°C was washed off the slant with sterile 0.1% peptone solution (Difco). The suspension was diluted with sterile 0.1% peptone to an optical density of 0.2 at 540 nm, (Spectronic 20 , Bausch and Lomb) to give a *S. typhimurium*^{NAR} population density of approximately 10^7 to 10^8 CFU/ml. Serial dilutions from this stock suspension were made to get desired inoculation levels. The actual number in the inoculum was determined by pour plating in triplicate, 0.1 ml of the dilution used as a source of the inoculum on BHI plates and counting CFU after 24 h incubation at 37°C.

Campylobacter jejuni: Cultures of *Campylobacter jejuni* (ATCC 29428) were also obtained from Dr. Mark Harrison. Inocula were prepared as described above except that *C. jejuni* was grown in brucella broth (Difco) at 42°C under a microaerophilic atmosphere. Number of organisms in appropriate dilutions of the

inoculum was determined by optical density measurements as above, and verified by surface plating. Populations of *C. jejuni* were determined by directly plating the samples on campylobacter blood-free selective media (modified CCDA-Preston with cefoperazone and amphotericin selective supplement; Oxoid, England, CM739+SR155). The plates were incubated in an atmosphere consisting of 10% CO_2 , 85% N_2 and 5% O_2 for 48 h at 42°C. The appearance of colonies on the petri plates was used to verify that the CFU was *C. jejuni*. Typical colonies of this strain were gray, moist, flat, and spreading. Smears from a typical colony were examined microscopically for further confirmation.

Inoculation and recovery

A marked area of skin 5.1 x 5.1 cm^2 was inoculated with the appropriately diluted inoculum by depositing a 100 µL volume with a micropipette and spreading this droplet evenly over the marked area with a sterile L-shaped glass rod. Following inoculation, the samples were held under a laminar-flow hood for 15 minutes to allow adsorption and attachment of the test organism. The drumsticks subjected to the RW and BSC/RW treatments were then immediately exposed to the RW. Surviving cells of either organism were recovered from the skin using skin maceration procedure. In the skin maceration technique, each marked skin area was aseptically cut and the piece was homogenized in a sterile stomacher bag with 100 ml of sterilized 0.1% peptone water in a Stomacher 400 lab blender (Seward Medical, London) for 60 sec. Serial dilutions of the homogenate were made with sterile peptone water (0.1%).

Viable *S. typhimurium*^{NAR} cells were enumerated using duplicate pour plate of Bismuth Sulfate agar (Difco Laboratories) supplemented with 200 ppm nalidixic acid (1-Ethyl-1,4-dihydro-7-methyl-4-oxo-1,8-napthyridine-3-carboxylic acid; Sigma Chemicals, St. Louis, MO). Plates were incubated at 37°C for 48 h. Typical colonies of *S. typhimurium*^{NAR} were brown or gray with a metallic sheen. The media surrounding the colony was usually brown at first, then turned black as the incubation increased. Recovered *S. typhimurium*^{NAR} populations were reported as $\log_{10}$ survivors per cm^2.

Viable *C. jejuni* cells were recovered using the same procedure of skin excision and maceration in a Stomacher, as above, except that the medium and procedure used for enumeration is as described above for this organism.

General statistics

Bacterial populations were converted to $\log_{10}$ prior to statistical analysis. Significant differences between treatment mean populations were determined by comparing each mean pair using the Student's t-test at $P < 0.05$.

RESULTS AND DISCUSSION

There has been no previous work on the combined effect of intense radiant heat and decontaminate animal carcasses (USDA, 1994). Our results demonstrated that the combined BSC/RW treatments exhibited significant synergistic interaction of these two microbiocidal treatments to amplify the extent of inactivation of inoculated pathogens.

Table 1 shows the log CFU of inoculated *S. typhimurium* and *C. jejuni* recovered from control and treated chicken drumsticks . With inocula smaller than 100 cells, there appears to be a problem with recovering the specified inoculum from the untreated inoculated surface. For example only 66% of control samples inoculated with an estimated 10 CFU of *S. typhimurium* was positive for this organism. This may be explained by the statistical probability of obtaining exactly the number of desired organisms when sampling from a very dilute solution. For example, when we took 6 - 100 µL aliquots from a suspension supposed to contain 100 CFU/ml, the actual counts from the aliquots obtained by plating were 11, 10, and 6 and 5, 9, and 13 . Actual recovery from the skin surface may not be 100% therefore introducing numerous numbers were necessary.

Also shown in Table 1 is the effect of different RWO treatments on *S. typhimurium*^{NAR} and *C jejuni* inoculated at different inoculum level. Drumsticks inoculated with either 10 or 100 CFU/drumstick exhibited no viable CFU of *S. typhimurium* after RW treatment. However, the same treatment on drumsticks inoculated with 1,000 CFU exhibited viable *S. typhimurium*. The combined BSC/RW treatment showed no recovered survivors from 1,000 CFU inoculum but there were survivors from 10,000 CFU inoculum. RW and BSC/RW treatments showed no *Campylobacter jejuni* survivor recovery up to 1,000 CFU inoculum but both treatments showed survivors when inoculum was 10,000 CFU. The BSC dip by itself had negligible microbiocidal effect.

Survivors recovered from an inoculum about 100 CFU of *S. typhimurium* decreased significantly as the radiant wall temperature (Table 2) for the same exposure time of 3 s. No recovered CFU of *S. typhimurium* were found on drumsticks treated at 788°C. Numbers of recovered survivors tested immediately after treatment and after 3 days 4°C were not significantly different. Gram negative bacteria possess a very thin peptidoglycan layer (Murray, et al., 1965) which may offer little protection against internal turgor pressure when the cytoplasmic membrane is weakened by high temperature (Mendonca et al., 1994). The fluidity of the cytoplasmic membrane is largely a reflection of membrane lipid composition (Beuchat, 1978). Katsui et al. (1981) suggested that the change in the fluidity of membrane lipids might be linked with heat resistance of bacteria. Bowler et al. (1973) suggested that the central cause of cellular heat injury is the disruption of the membrane lipoprotein complexes or enzymes, associated with the integrity of the cell membrane.

The combined BSC/RW treatment had an synergistic effect on salmonellae and campylobacters. Table 3 shows the effect of different treatments on these pathogens. The analysis showed a consistent statistically significant difference between the control group and the three treatment groups. Neither of the individual RW or BSC treatments achieved a high degree of pathogen reduction, but when the treatments were combined, the effects were more notable. The reductions were 2.32 log for *S. typhimurium*^{NAR} and 3.36 for *Campylobacter jejuni* respectively. Relating this to risk, if we assume, in the worst case, that 70% of chickens in supermarkets are contaminated with salmonellae

and their numbers on chicken drumsticks follows a Poisson distribution, then the most probable number of salmonellae per drumsticks is Ln 100 – Ln 30 = 1.204 and the probability of no *Salmonella* on a drumstick is p = 0.30. If decontamination treatment reduced the number of *Salmonella* 100 fold, the most probable number becomes 0.01204 and the probability of no *Salmonella* on a chicken becomes 0.988. Supposing that an average family buys one pack of chicken drumsticks a week and assuming a binomial sampling distribution with P = 0.988 for selecting a contaminant pack, we have P = 1 - [(52 !/ 0 ! 52 !) 0.988^{52}] = 0.466 or nearly a 50 % chance that in 1 year of weekly purchase, at least one of the purchases will be contaminated. Furthermore, Bryan (1979) reported that the lowest dose of several species of *Salmonella* producing a clinical response in healthy adult humans was 10^5 CFU. As our studies noted above, a RWO treatment of 788°C for 3 sec would be expected to reduce the population of *S. typhimurium*^{NAR}/cm^2 by 2.32 logs. Thus a population of 1,000 *S. typhimurium*^{NAR}/cm^2 would decrease to approximately less than 500 cells, well below the estimated infectious dose, and a very large amount of raw RWO treated chicken would be necessary for an infectious dose to a healthy adult. Further, it has been demonstrated that heat-injured *Salmonella* are much more sensitive to the effects of cooking than non heat-injured organism. We thus concluded that treating chicken drumsticks in RWO at 788°C for 3 sec should provide significant protection against the presence of these Gram negative pathogens.

It could be argued that the presented data are valid for challenge test with the organisms and would not reliably indicate the destruction of natural contaminants of these pathogens. To investigate this possibility 10 "pairs" of refrigerated chicken drumsticks were randomly purchased at local retail outlets. One member of each pair was directly examined for its level of salmonellae. While the other member was similarly examined but after BSC/RW treatment. The results are presented in Table 4. The mean salmonella count of the 10 untreated samples was 356 cells/drumsticks with a range of 0 to 3550 cells/drumsticks. The mean count of 10 treated carcasses was 13 cells/drumsticks with a range of 0 to 97 cells/drumsticks. 8 of the untreated samples were positive for salmonella contamination whereas only 3 of the treated samples were positive. Thus it was shown that BSC/RW treatment is also effective against natural contaminants of salmonellae.

CONCLUSION

A combination of radiant heat and buffered sodium citrate, pH 5.8, significantly reduced or eliminated Gram-negative pathogens on chicken skin without causing a departure of appearance from the raw product. The treatment was effective for inoculum levels up to 1,000 CFU for both *S. typhimurium and C. jejuni.*

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TABLE 1. Recovery of *S. typhimurium*[NAR] and *Campylobacter jejuni* inoculated on chicken drumsticks and exposed 3 s to a radiant wall (RW) at 788°C with or without pretreatment with 1-min dip in 6% buffered sodium citrate (BSC).

Organism	Inoculum (cell)	Control	BSC	RW	BSC/RW
Salmonella	0	*	ND[B]	ND	ND
	10	0.95[A]	*	*[C]	*
	100	1.89	1.53	*	*
	1,000	2.91	2.33	0.77	*
	10,000	3.94	3.77	1.76	1.55
C. jejuni	0	ND	ND	ND	ND
	10	ND	ND	ND	ND
	100	2.01	1.23	*	*
	1,000	2.98	2.69	*	*
	10,000	3.87	3.80	1.48	0.93

[A] Bacterial count is expressed as $\log_{10}$ of numbers per cm^2

[B] ND – not done

[C] * – not detected

TABLE 2. Recovery of injured nalidixic acid resistant *Salmonella typhimurium* (*S. typhimurium*^{NAR}) inoculated on skins of chicken drumsticks at a level of about 100 CFU and exposed to different RW temperature.

RW t (°C)	Days 0 storage at 4°C			Days 3 storage at 4°C		
	Replicate		Total	Replicate		Total
	1	2		1	2	
649	10/10[a]	9/10	19/20	10/10	10/10	20/20
704	7/10	5/10	12/20	8/10	7/10	15/20
788	0/10	0/10	0/20	0/10	0/10	0/20

[a] First number in body of table represents number of drumsticks showing positive for *S. typhimurium*^{NAR} ; e.g.: 10/10 indicates 10 drumsticks confirmed as positive for *S. typhimurium*^{NAR} out of 10 drumsticks

TABLE 3: . Comparison of recovery of *S. typhimurium*^{NAR} and *Campylobacter jejuni* inoculated on chicken drumsticks and exposed 3 s to a radiant wall (RW) at 788°C with or without pretreatment with 1-min dip in 6% buffered sodium citrate (BSC).

Treatments	Log counts (mean ±SE)[A]	
	Salmonella typhimurium	*Campylobacter jejuni*
Control	7.22 ± 0.11[a]	7.41 ± 0.23[a]
BSC	6.43 ± 0.51[b]	5.96 ± 0.44[b]
RW	5.49 ± 0.32[c]	5.00± 0.12[c]
BSC/RW	4.90± 0.15[d]	4.05 ± 0.05[d]

[A]Mean values in the same column within the same microorganism that are not followed by the same letter are significantly different

TABLE 4 : Effect of RW treatment on the actual number of indigenous *Salmonella* on chicken drumsticks skin. Cells were recovered using the rinse method on whole drumsticks.

Sample number	Control (No treatment)	RW
1	6	0
2	14	0
3	0	0
4	139	26
5	2	0
6	3550	97
7	13	7
8	6	0
9	11	0
10	0	0

CHAPTER 6

CONCLUSIONS

Radiant heat from a high temperature radiant wall induced microbicidal effects on surfaces of whole broilers without cooking the surface. An exposure for 5 s at 649°C with a 1-min dip in 1% buffered sodium citrate solution induced more than 1.5 log reduction in TPC. Assuming proper refrigeration is maintained during distribution and retail, RW treatment results in improved microbiological quality and potentially greater shelf-life and safety for raw poultry parts. Adding a 6% BSC solution dip before RW exposure for only 3 s at 788°C greatly increased the shelf life. Quick chilling of RW treated chicken drumsticks was ineffective on microbial quality. The epidermis on the chicken skin plays a vital role on the keeping quality. In general, when epidermis is left on the skin, the shelf life of RW treated drumsticks was increased due to better exposure of microorganisms to radiant heat facilitating their destruction. Same combination of radiant heat and buffered sodium citrate, pH 5.8, significantly reduced or eliminated Gram-negative pathogens on chicken skin without causing a departure of appearance from the raw product. The treatment was effective for inoculum levels up to 1,000 CFU for both *S. typhimurium* and *Campylobacter jejuni*.

Application of radiant heat as a microbiological decontamination process for raw poultry has produced 1 - 3 log reductions of indigenous microflora and inoculated pathogens without inducing manifestation of cooking in the products.

Treatments which reduce salmonellae levels by 2 log units should be effective in controlling this pathogens, because salmonellae levels on broiler carcasses are typically < 100 CFU per carcass. Against *Salmonella typhimurium* and *Campylobacter jejuni*, our process reduced these pathogens to no recoverable CFU from inocula of 1,000 CFU. Our main objective of extending the shelf life of raw poultry was achieved, the shelf life of RW treated poultry was double those of controls.

Buffered sodium citrate (BSC) was effective in increasing the lethality of the radiant heat treatment, but does not have the lethal effects necessary for it to be a primary means of food preservation. BSC was a contributor to the "hurdle" approach to food preservation and food safety. Resistance of a food product to growth or survival of spoilage or pathogenic microorganisms is determined by the number of intrinsic (e.g., heat treatment) and extrinsic (e.g., storage temperature) "barriers" which act as "hurdles" for microorganisms to overcome. The more hurdles or barriers, the more difficult it becomes for a target microorganism to grow or survive. In contrast to biostatic barriers which simply inhibit the growth of contaminating microbes (e. g. modified atmosphere packaging), BSC can serve as a bactericidal barrier helping to reduce the levels of potential spoilage or pathogenic microorganisms. Our studies indicate that BSC combined with radiant heat was effective for fresh poultry pasteurization to increase microbial lethality of a heat treatment thus enhancing the safety and shelf life of refrigerated poultry products.

APPENDIX

INFRARED TEMPERATURE MEASUREMENT ON CHICKEN DRUMSTICKS TREATED IN A RADIANT WALL OVEN

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INFRARED TEMPERATURE MEASUREMENT ON CHICKEN DRUMSTICKS TREATED IN A RADIANT WALL OVEN

SUMMARY

Infrared temperature measuring devices are highly developed sensors for non-contact temperature measurement and have widespread application in industrial processing and research. This essay describes in non-mathematical term the theory upon which the measurement technology is based and its application in our process. ThermaCAM (Model PM 280, Inframetrics, Inc.), a palm-size focal plane array (FPA) radiometer with full-screen temperature measurement and built-in image storage and analysis capabilities, was used to measure the surface temperatures of chicken drumsticks exposed 3 s to a radiant wall (RW) at 788°C (1450°F). Emissivity of the chicken drumsticks with skin was determined to be 0.93 and that of skinless drumstick was 0.90. The mean surface temperature of chicken drumsticks (skin on) was increased in 3 s from 51.9 to 218.4°F. Even 10 s after the treatment, whole surface area of the drumsticks had temperature of 160°F or more. Similar treatment of skinless drumsticks could achieve an average temperature of only 161.1°F with only 50 % of the area had temperature of 160°F or more.

INTRODUCTION

Electromagnetic waves traveling through space may be intercepted by a suitable surface and absorbed, raising the energy level of the intercepting surface. When the electromagnetic waves have the frequency of light, the phenomenon is referred to as *radiation* (Toledo, 1991). All materials at temperatures higher than absolute zero (0°Kelvin) emit energy in proportion to the fourth power of their temperature. Hotter matter releases more energy than cooler matter. Like convection, radiant heat transfer is a surface phenomenon and the conditions at the surface determine the rate of heat transfer. Radiant heat transfer generally involves the range of electromagnetic waves called infrared radiation. An infrared thermometer measures temperature by detecting the infrared energy emitted by materials. The most basic design consists of a lens to focus the infrared (IR) energy on to a detector, which converts the energy to an electrical signal that can be displayed in units of temperature after being compensated for ambient temperature variation. This configuration facilitates temperature measurement from a distance without contact with the object to be measured. As such, the infrared thermometer is useful for measuring temperature under circumstances where thermocouples or other probe type sensors cannot be used or do not produce accurate data for a variety of reasons. Some of the typical circumstances are where the object to be measured is moving; where the object is surrounded by an EM field, as in induction heating; where the object is contained in a vacuum or other controlled atmosphere; or in applications where a fast response is required. Designs for an infrared

thermometer (IRT) have existed since at least the late nineteenth century, and Darling (1911) discussed various concepts. However, it was not until the 1930's that the technology was available to turn these concepts into practical measuring instruments. Since that time there has been considerable evolution in the design and a large amount of measurement and application expertise has accrued. At the present time, the technique is well accepted and is widely used in industry and in research.

Measurement Principles

Infrared radiation is part of the Electromagnetic Spectrum and occupies frequencies between visible light and radio waves. The IR part of the spectrum spans wavelengths from 0.7 micrometers to 1000 micrometers (microns) as shown in Figure 1. Within this wave band, only frequencies of 0.7 microns to 20 microns are used for practical, everyday temperature measurement. This is because the IR detectors currently available to industry are not sensitive enough to detect the very small amounts of energy available at wavelengths beyond 20 microns.

Though IR radiation is not visible to the human eye, it is helpful to imagine it as being visible when dealing with the principles of measurement and when considering applications, because in many respects it behaves in the same way as visible light. IR energy travels in straight lines from the source and can be reflected and absorbed by material surfaces in its path. In the case of most solid objects, which are opaque to the human eye, part of the IR energy striking the

object surface will be absorbed and part will be reflected. Of the energy absorbed by the object, a proportion will be re-emitted and part will be reflected internally. This will also apply to materials, which are transparent to the eye, such as glass, gases and thin, clear plastics, but in addition, some of the IR energy will also pass through the object (Figure 2). These phenomena collectively contribute to what is referred to as the *emissivity* of the object or material.

Materials which do not reflect or transmit any IR energy are know as Blackbodies and are not known to exist naturally. However, for the purpose of theoretical calculation, a true blackbody is given a value of 1.0. The closest approximation to a blackbody emissivity of 1.0, which can be achieved in real life is an IR opaque, spherical cavity with a small tubular entry (Figure 3). The inner surface of such a sphere will have an emissivity of 0.998. Different kinds of materials and gases have different emissivities, and will therefore emit IR at different intensities for a given temperature. The emissivity of a material or gas is a function of its molecular structure and surface characteristics. It is not generally a function of color unless the source of the color is a radically different substance to the main body of material. A practical example of this is metallic paints, which incorporate significant amounts of aluminum. Most paints have the same emissivity irrespective of color, but aluminum has a very different emissivity, which will therefore modify the emissivity of metallized paints.

Just as is the case with visible light, the more highly polished some surfaces are, the more IR energy the surface will reflect. The surface characteristics of a material will therefore also influence its emissivity. In

temperature measurement this is most significant in the case of infrared opaque materials which have an inherently low emissivity. Thus a highly polished piece of stainless steel will have a much lower emissivity than the same piece with a rough, machined surface. This is because the grooves created by the machining prevent as much of the IR energy from being reflected. In addition to molecular structure and surface condition, a third factor affecting the apparent emissivity of a material or gas is the wavelength sensitivity of the sensor, known as the sensor's spectral response.

Theoretical Basis for IR Temperature Measurement

The formulas upon which infrared temperature measurement is based are old, established and well proven. It is unlikely that most IRT users will need to make use of the formulas, but knowledge of them will provide an appreciation of the interdependency of certain variables, and serve to clarify the foregoing text. The important formulas are as follows:

1. Kirchoff's Law

When an object is at thermal equilibrium, the amount of absorption will equal the amount of emission.

2. Stephan Boltzmann Law

The hotter an object becomes the more infrared energy it emits.

3. Wien's Displacement Law

The wavelength at which the maximum amount of energy is emitted becomes shorter as the temperature increases.

4. Planck's Equation

Describes the relationship between spectral emissivity, temperature and radiant energy.

Infrared Thermometer Design and Construction

A basic infrared thermometer (IRT) design, comprises a lens to collect the energy emitted by the target; a detector to convert the energy to an electrical signal; an emissivity adjustment to match the IRT calibration to the emitting characteristics of the object being measured; and an ambient temperature compensation circuit to ensure that temperature variations within the IRT, due to ambient changes, are not transferred to the final output. The modern IRT is founded on this concept (Fig. 4), but is more technologically sophisticated to widen the scope of its application. Probably the most important advance in infrared thermometry has been the introduction of selective filtering of the incoming IR signal, which has been made possible by the availability of more sensitive detectors and more stable signal amplifiers. Whereas the early IRT's required a broad spectral band of IR to obtain a workable detector output, modern IRT's routinely have spectral responses of only 1 micron. The need to have selected and narrow spectral responses arises because it is often necessary to either see through some form of atmospheric or other interference in the sight path, or in fact to obtain a measurement of a gas or other substance which is transparent to a broad band of IR energy. Some common examples of selective spectral responses are 8-14 microns, which avoids interference from

atmospheric moisture over long path measurements; 7.9 microns which is used for the measurement of some thin film plastics; and 3.86 microns which avoids interference from CO_2 and H_2O vapor in flames and combustion gases. The choice between a shorter, or longer wavelength spectral response is also dictated by the temperature range because, as Planck's Equation shows, the peak energy shifts towards shorter wavelengths as the temperature increases (Planck, 1959). Applications, which do not demand selective filtering for the above stated reasons, may often benefit from a narrow spectral response as close to 0.7 microns as possible. This is because the effective emissivity of a material is highest at shorter wavelengths and the accuracy of sensors with narrow spectral responses is less affected by changes in target surface emissivity.

It is apparent that emissivity is a very important factor in infrared temperature measurement. Unless the emissivity of the material being measured is known, and incorporated into the measurement, it is unlikely that accurate data will be obtained. There are two methods for obtaining the emissivity of a material: a) by referring to published tables and b) by comparing the IRT measurement with a simultaneous measurement obtained by a thermocouple or resistance thermometer and adjusting the emissivity setting until the IRT reads the same. Fortunately, the published data available from the IRT manufacturers and some research organizations is extensive, so it is seldom necessary to experiment. As a rule of thumb, most opaque, non-metallic materials have a high and stable emissivity in the 0.85 to 9.0 range; and most un-oxidized, metallic materials have

a low to medium emissivity from 0.2 to 0.5, with the exception of gold, silver and aluminum which have emissivities in the order of 0.02 to 0.04 and are, as a result, very difficult to measure with an IRT. While it is almost always possible to establish the emissivity of the basic material being measured, a complication arises in the case of materials, which have emissivities that change with temperature such as most metals, and other materials such as silicon and high purity, single crystal ceramics. Some applications, which exhibit this phenomenon, can be solved using the two-color ratio method (Sparrow and Cess, 1966). This technique is not dissimilar to the infrared thermometers described so far, but measures the ratio of infrared energy emitted from the material at two wavelengths, rather than the absolute energy at one wavelength or wave band.

Temperature measurement of chicken drumsticks

Fresh (not previously frozen) chicken drumsticks with skin from the same producer were obtained from a local supermarket 1-2 hours before treatments. They were divided in two groups. One group was exposed to 3s radiant heat at 1450 °F RW temperature. The second group was similarly treated, but only after removing the skin. Surface temperature of the drumsticks was measured by taking images of drumsticks at various processing stages by a palm-sized focal plane array radiometer (ThermaCAM PM 280) supplied by Inframetrics, Inc., North Billerica, MA (Fig. 5). ThermaCAM uses a 256 X 256 platinum silicide focal plane array (FPA) detector, which provides a superior image without the

use of mechanical scanning. An integrated closed-cycle cryogenic cooler maintains the detector temperature. Images are displayed on a color viewfinder, and can be output as standard video or S-Video. Data can be stored on removable solid-state PCMCIA memory cards. Calibrated IR data is output as TV and VCR-compatible video for extensive real-time data analysis. Data analysis was performed by ThermaGRAM95® windows-based software program manufactured by Thermoteknix Systems Ltd., Cambridge, England. This software performs real-time analysis on live or stored images. ThermaCAM transfers live images to ThermaGRAM via the TGRAM output port. Static images can be transferred to ThermaGRAM via the PCMCIA ImageBank memory card.

In order to measure the surface temperature we first tried to measure with an infrared gun Raynger II plus made by Raytek, CA, This portable instrument (Fig. 6) measures surface temperature without contact. The instrument collects the infrared energy radiated by a target and computes its surface temperature. But because our sample was being processed at high speed (64.8 ft/sec) we were not able to shoot the gun on the sample. Even if we were successful, the high wall temperature would have generated so much background noise that it would not give an accurate measurement.

Later, we experimented with temperature indicating liquid. OMEGALAQ Temperature Indicating Liquids consist of a temperature melt material in a liquid form. They are used to tell temperatures on surfaces and are widely used for monitoring critical temperatures in electronics field, such as preheat temperatures for wave soldering. Other applications include electric heatsealing,

postforming plastic laminate, and annealing polished metal surfaces. These liquids have a time response on the order of milliseconds (0.001 sec). Heating to a temperature well above the melting point, these liquids are subject to some sublimation. We used liquids for 182, 188, 194, and 200°F on chicken drumsticks (Fig. 7). These were good indicators and we got melting of all these liquid, indicating that our process raised the temperature of the drumsticks above 200 °F. The problem with these liquids were that the evaluations were subjective. And also it was difficult to use these liquids on a wet surface like chicken drumsticks.

Finally, we went for hi-tech measurement with ThermaCAM and Fig. 8 – 14 represents actual images and histograms of temperature measurment of chicken drumsticks. Table. 1 presents the change in surface temperature over time of fresh skin-on chicken drumsticks treated by RWO. To evaluate the efficacy of our process, we set a cutoff temperature of 160°F (USDA/FSIS recommended temperature for *Salmonella* elimination) above which we need to keep our sample for sufficient time to eliminate pathogens like salmonella. Our analysis showed that initially the drumsticks received sufficient heat. Because of the biological nature of the drumsticks we did not get a uniform temperature over the drumstick surface. Cooler spots were observed on areas of bare skin and hotter spots were observed on areas with high fat content. The unequal temperature distribution could also be due to unequal distances from the radiant wall. This can be controlled by changing the design of the wall configuration. As for biological factor, if we use uniform drumsticks from a single flock, it can be minimized. However, it is not the uniformity of temperature that will determine the

efficacy of our process, rather the lowest temperature on the drumsticks should be high enough to kill the organism. We can hypothesize, that on the areas that did not receive/hold sufficiently our selected temperature, the organisms will be sub-lethally injured and will require optimum environmental conditions to enable repair of sub-lethal damage. For this reason, the combined effect of treatment with radiant heat in conjunction with other modes of preservations can be used to achieve low populations of viable cells initially and control growth during storage.

When the effect of radiant heat on skinless drumsticks compared to drumsticks with skin were analyzed, we found the skinless drumsticks received significantly less heat than their skin-on counterparts (Table 2). This could be due to evaporative cooling of the wet skinless tissue at high temperature. However, unless a detailed microbiological study is carried out, it is difficult to see the implications of these lower temperatures. Skin tissues and muscle tissues have different properties that might influence the destruction/survival of the microorganisms.

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TABLE 1. Change in surface temperature over time of fresh skin-on chicken drumsticks exposed 3 s to a radiant wall at 788°C (1450°F)

Time (sec)	Surface temperature in °F			
	Minimum	Maximum	Average	% area above 160°F
0	175.3	248.0	218.4	100
5	173.1	248.0	209.4	100
10	165.4	248.0	199.5	100
15	114.5	248.0	144.4	21
20	97.8	248.0	136.3	15

TABLE 2. Comparison between surface temperature profiles of fresh skin-on and skinless chicken drumsticks exposed 3 s to a RW at 788°C (1450°F)

Chicken Drumsticks	Surface temperature in °F			
	Minimum	Maximum	Average	% area above 160°F
Skin-on	175.3	248.0	218.4	100
Skinless	116.7	248.0	161.1	49

Fig. 1 : Electromagnetic spectrum (Infrared spectrum 0.7 to 1,000 microns)

Fig. 2 : Radiative heat exchange

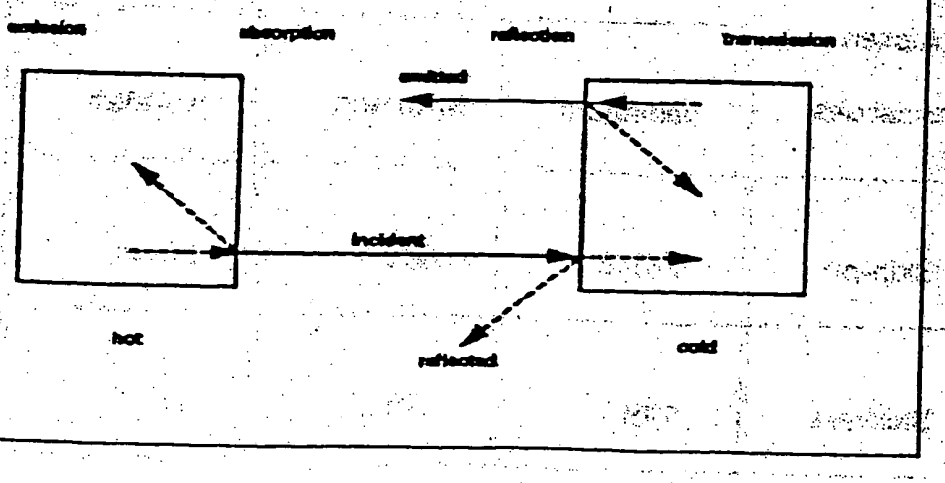


Fig. 3 : Emissivity

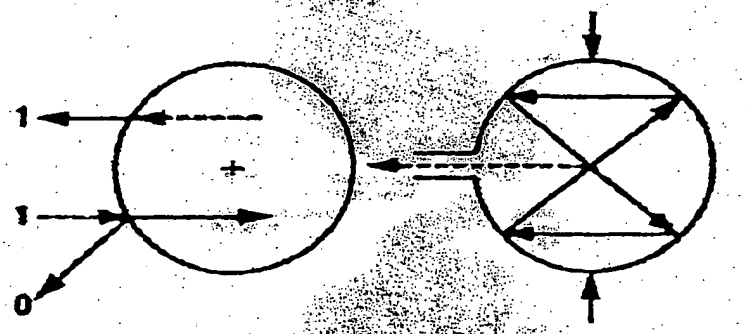


Fig. 4 : Infrared temperature measurment

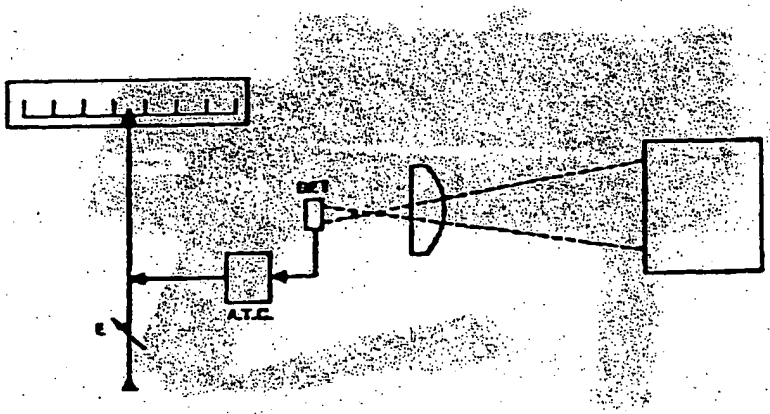


Fig. 5 : ThermaCam PM 280

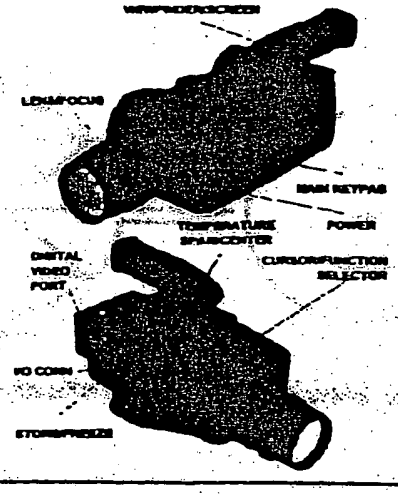


Fig. 6 : Infrared gun Raynger II

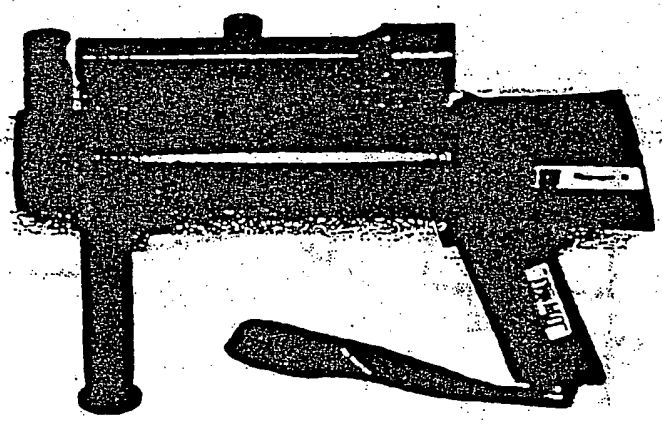


Fig. 7 : Temperature-sensitive paints on chicken drumsticks exposed 3 s to a RW at 1450 °F

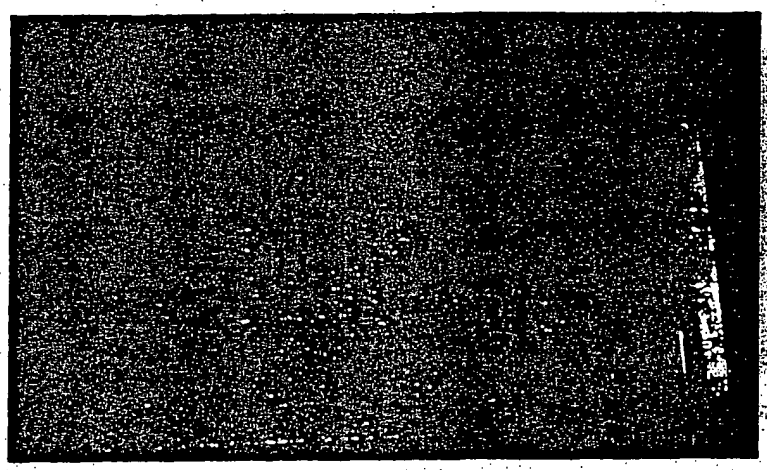
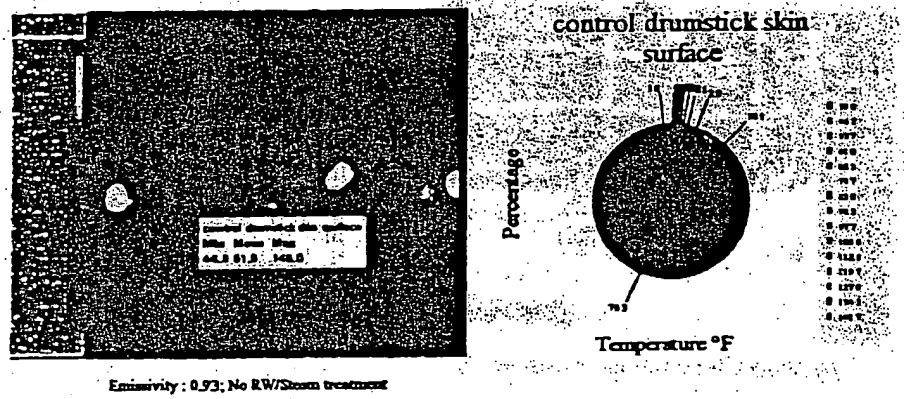


Fig.8 : Surface temperature profile of chicken drumstick skin before RW/Steam treatment



Emissivity : 0.93; No RW/Steam treatment

Fig. 9 : Surface temperature profile of chicken drumstick skin right after RW/Steam treatment

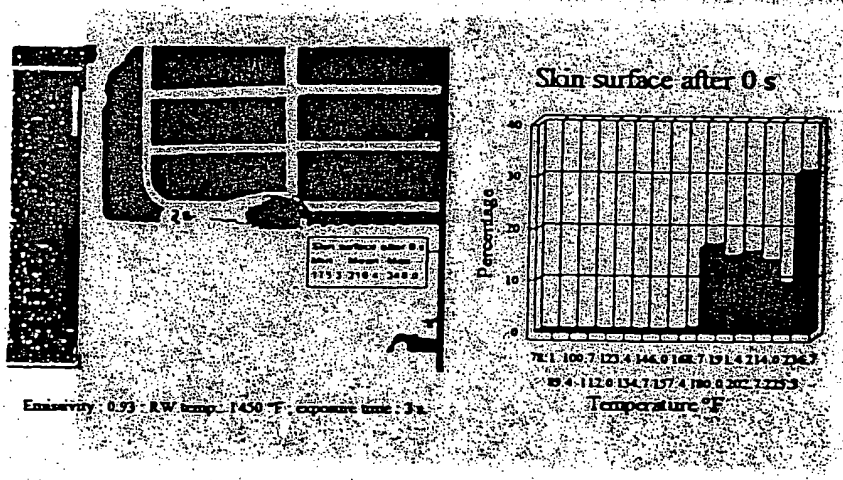


Fig. 10 : Skin surface temperatures 5 sec after RW/Steam treatment

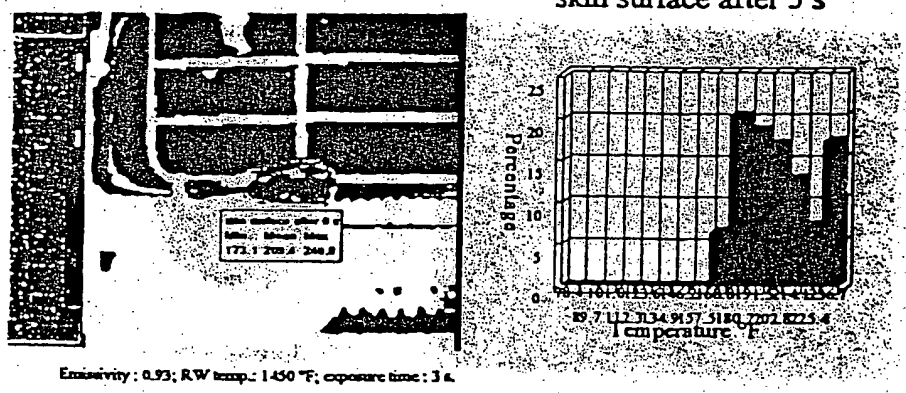
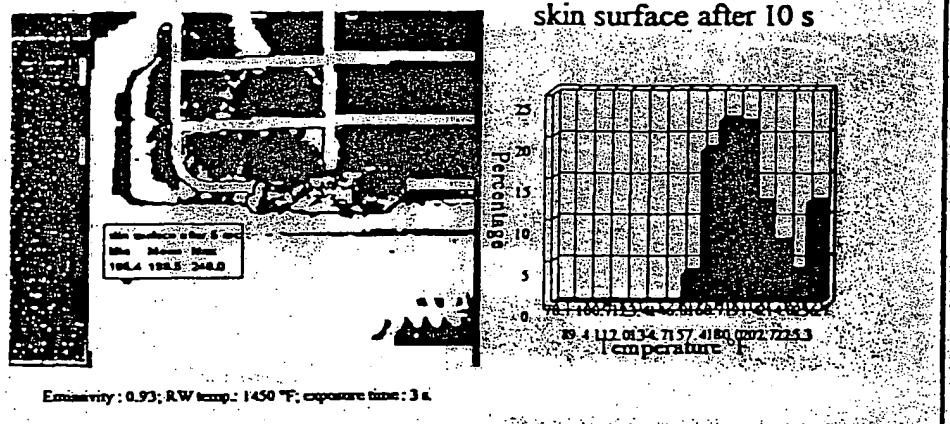
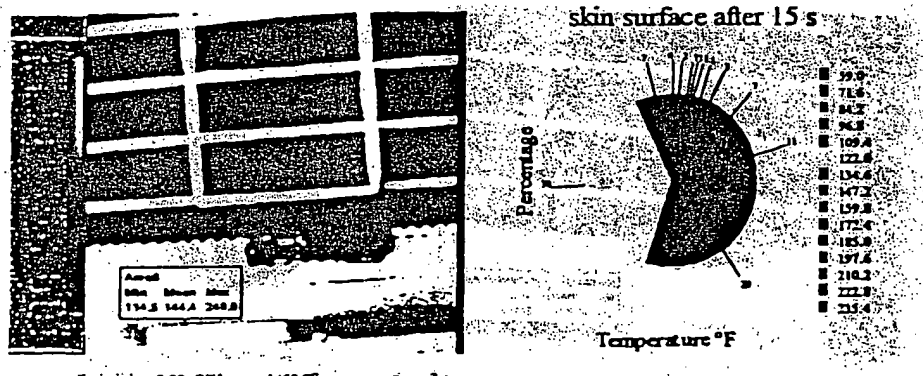


Fig. 11 : Skin surface temperatures 10 s. after RW/Steam treatment



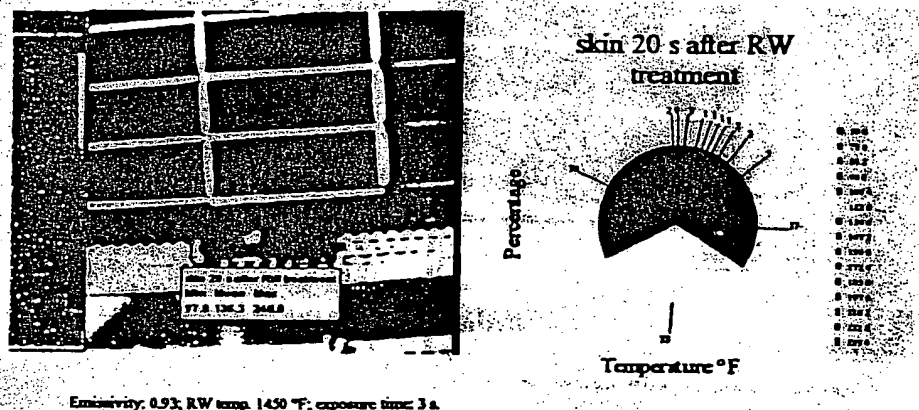
Emissivity : 0.93; RW temp.: 1450 °F; exposure time : 3 s

Fig. 12 : Skin surface temperatures 15 s after RW/Steam treatment



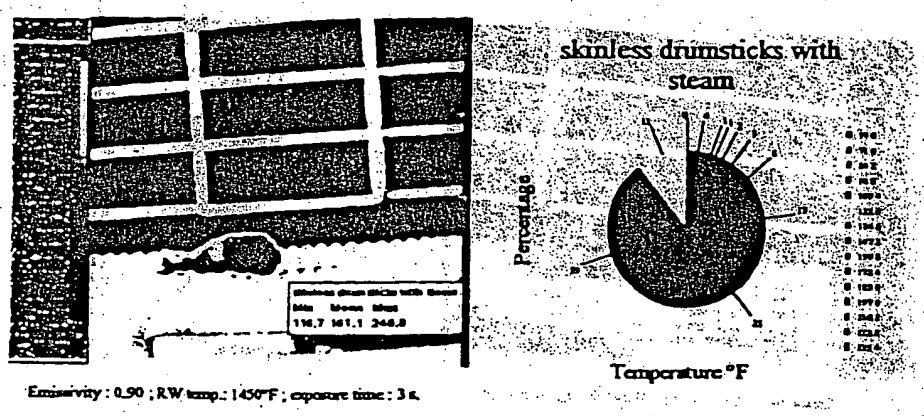
Emissivity: 0.93; RW temp. 1450 °F; exposure time: 3 s

Fig. 13 : Skin surface temperatures 20 s after RW/Steam treatment



Emissivity: 0.93; RW temp. 1450 °F; exposure time: 3 s.

Fig 14 : Surface temperature profile of RW/Steam treated skinless chicken drumsticks



Emissivity : 0.90 ; RW temp.: 1450°F ; exposure time : 3 s.